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Digital Design and Management Services

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General Practitioner Cloud Solution [GP-VPC]

Abstract

During the coronavirus pandemic, a GP decides to move his surgery to the cloud in the hope that he will be able to test more patients. He recruits a cloud architect to design and report on the architecture. This report outlines a deep dive into AWS, and considers the potential for a cloud surgery. Looks at numerous services provided by AWS, and documents the processes used to prototype the cloud surgery.

Contents

1 Introduction

A General Practitioner (GP) has decided to move his information system to the cloud. He predicts that with the coronavirus pandemic his surgery will become very busy. He speaks to a team of developers and asked them to come up with a report detailing; feasibility, usability, cost efficiency, security, reliability and performance. The GP would also like to know the reasons for our choice of data center, cloud platform, and services. And finally the GP would like a prototype of the system.

Cloud computing has many advantages over a traditional computing environment. For example, capital expense is replaced with variable expense. This means our GP will no longer have to make large investments in computer hardware. Cloud Service Provider (CSP) economies of scale, which ensures our GP will pay minimum costs for operating in the cloud, a benefit from the many thousands of cloud users the CSP has already registered. Stop guessing capacity, increased speed and agility the list is endless.

This report discusses cloud computing, determines if a GP surgery could be based in the cloud, and looks at the architecture of cloud systems that could meet the needs of the GP. The sections are logically laid out, starting with a requirements analysis and finishing with a conclusion.

2 Requirements Analysis

The system modelled in this report acts as a starting point, a base from which the GP can continue to develop and improve the system and its processes. The purpose of this system is to update and upgrade the GP's old on-premises information system to that of a new elastic cloud based system.

The GP needs to communicate with all his patients, keep confidential records of their health, financial transactions and contact details. He needs to keep records of receptionists and nurses; wages, timekeeping and rota. Finally, he needs to migrate data from an on-premises environment to the cloud.

The key characteristic of this system is the data it holds. It is sensitive, protected by law and extremely valuable. The data must be available to all personnel authorised to access it, there must be no failure, data loss or theft. The system must be cost efficient and perform under extreme conditions. The table below lists the functional and non-functional requirements for the cloud system. This is not an exhaustive list of requirements.

Non-Functional Requirements
Compliance
Usability
Reliability
Performance
Supportability
Cost efficiency
Efficiency
Availability
Scalability
Simple to use

Functional Requirements
Database
Compute
Web Server
Lambda Functionality
Storage
Respond to security threats (automated)
Management (simplified)
External and Internal Interface
Security
Network

An Interface is required where staff can update data, patients can book appointments, and the Doctor can access patient records. The system must be able to respond to security threats and be automated where possible. The system should be simple to manage, the Doctor should not have to spend too much time administering.

Although the GP will not have time to manage the system, there are legal requirements and data protection laws that dictate what type of deployment model is compliant. Infrastructure as a Service (IaaS) is described by Rountree and Castrillo (2013, pp 70) as "*computing power, storage, networking and operating systems"*. IaaS provides the bare bones of a system, meaning that all compliance laws and regulations can be strictly adhered to because the GP is in control.

2.1 Cloud Service Provider (CSP)

The choice of data center relates directly to the choice of service provider. Amazon Web Services (AWS) is by far the largest service provider with global infrastructure worth billions. The services they provide are well documented and user friendly. The well architected framework, discussed in the next section, provides a set of questions and guides on how to best implement a cloud system. The framework and our non-functional requirements are synchronised.

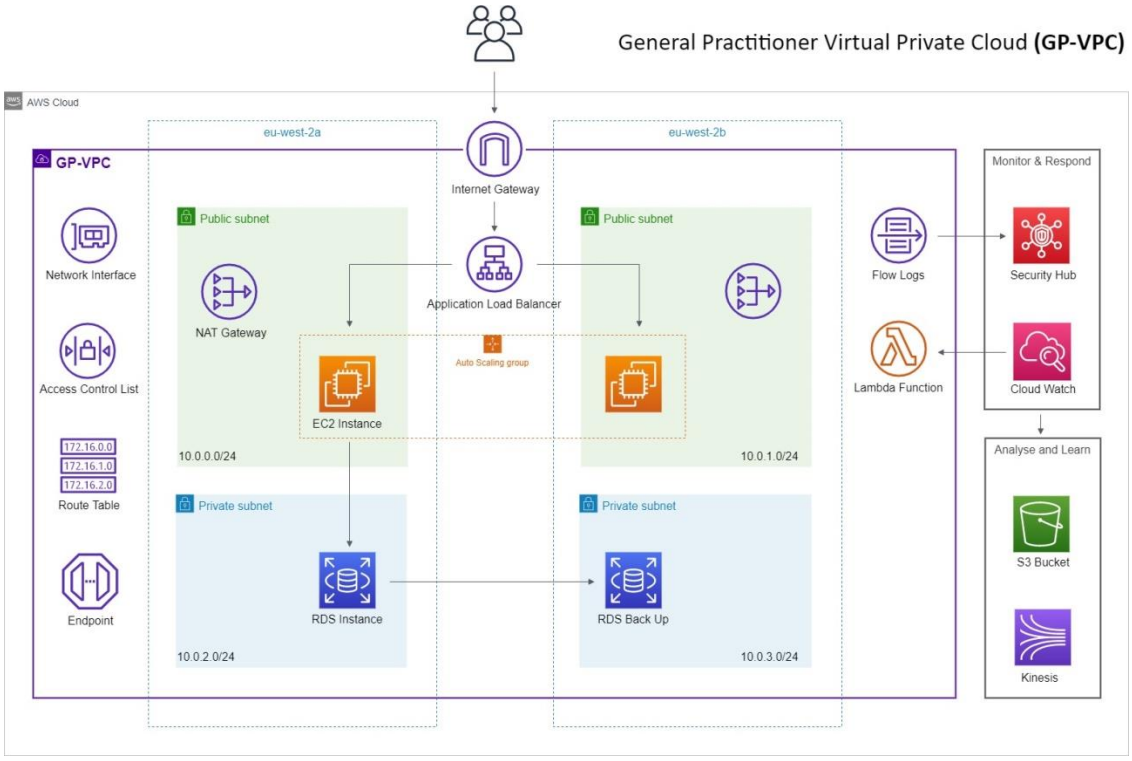
The type of data held by our GP is sensitive and structured with complex relationships. Amazon Relational Database Service (RDS) provides numerous options for a database engine. MySQL, one of the RDS options, can handle millions of requests and has first class security configurations. A detailed description of the configurations is in **Appendix A. section 1.3.** Amazon Elastic Compute (EC2) services include; Auto Scaling and Load Balancing, both are functional requirements, and are discussed in more detail later in this report.

3 Cloud Architecture

Wikipedia (2020) states that, *"Cloud Architecture refers to the components and subcomponents required for cloud computing. These components typically consist of a front end platform (fat client, thin client, mobile device), back end platforms (servers, storage), a cloud based delivery, and a network (Internet, Intranet, Intercloud). Combined, these components make up cloud computing architecture".* This section describes the features and components of the GP-VPC Cloud Architecture, and using the CLI, demonstrates a peering connection. The RDS and EC2 are also discussed along with some of the services integrated with the VPC.

3.1 System Walkthrough

The system starts with a user request. The user could be a patient, a medical professional, or the GP himself. Accessing the system requires the user to verify their identity using Identity and Access Management (IAM) and Multi-Factor Authentication (MFA). Once the user is authorised and their request is processed, they are directed to the Internet Gateway.



The Internet Gateway acts a bridge between the VPC and the Internet. The VPC is protected by Shield, which is a managed service provided for free by AWS. Shield protects against Distributed Denial of Service (DDoS) attacks.

The request must then pass through the Application Load Balancer, which directs incoming traffic and increases availability by sending traffic to healthy instances. The EC2 web server receives the request and responds with either the web page or database results requested. The diagram also illustrates some of the components within our VPC. For example, the Route tables, which control traffic going out of the subnets and Access Control Lists, which control traffic entering the subnets. Subnets are used to separate VPC's and may be public or private. Private subnets do not have direct access to the Internet, while public subnets do have direct access. Its important to note that the Application Load Balancer, EC2 and RDS instances are all protected by security groups within the VPC.

The Monitor and Respond section of the system, on the right of the image, is designed to comply with the AWS well architected framework. The Flow Logs, one of the components in our VPC, feeds the Security Hub data on network activity. The Security Hub is a collection of security services combined into one simple centralised interface. A detailed description and architect drawing of the monitor and respond section is in the next section**.**

The Security Hub then sends the data to CloudWatch where a response is either required or the data is sent to an S3 bucket. If a response is required CloudWatch Events alert the Lambda Function to take action. The action could be shutting down the entire or part of system. The function could also be programmed to send a notification email. An example of system notifications is available in Appendix A. section 1.4.

The final part of the system is data analysis. Kinesis provides a powerful tool that could be used to analyse and improve system performance, cost or security. The architecture is based on an AWS well architected framework principle, learn from mistakes. The Monitor and analyse section is designed to reduce costs, improve performance and efficiency by monitoring and learning from the system.

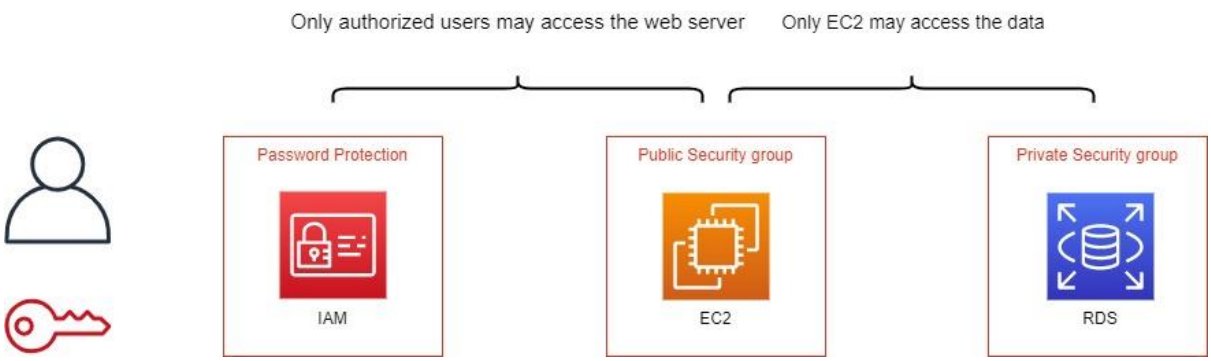
Reliability is hard wired into the system, by using multiple availability zones, an auto scaling group and application load balancer. Even the replicated database ensures fault tolerance. Security is evident on every layer. The user must access the system via IAM and MFA, Shield and WAF protect the resources, while Guard Duty monitors and reports on activity. Indeed, even at the network layer Access Control Lists are used to protect the system.

3.2 Identity and Access Management

At this point, it is important to discuss the difference between authorisation and authentication, IAM manages both. This section will also discuss the shared responsibility model and how it affects the GP-VPC, and its components. UK NHS compliance is also briefly covered.

As previously discussed in the requirements analysis the key characteristic of the data in the GP-VPC is its value. Access to the data is a security priority. IAM and Multi-Factor Authentication (MFA) provide the solution. IAM is a *"web service that helps you securely control access to AWS resources. You use IAM to control who is authenticated (signed in) and authorized (has permissions) to use resources"*. The image below illustrates the role IAM plays in securing the GP data. For each layer of security authorisation is required while MFA manages with authentication. An example of the json files used to control access to data can be found in Appendix E. section 5.2

Example IAM Authorisation



The NHS is an organisation that must adhere to UK compliance regulations and laws. For example, the data protection act of 2018 https://www.gov.uk/government/collections/data-protection-act-2018, which enforces strict control of data held by organisations.

3.2.1 The Shared Responsibility Model

The Shared Responsibility Model refers to sharing of security for resources in the cloud. The cloud service provider (CSP) is responsible for the managing of infrastructure or of the cloud and the cloud service customer (CSC) is responsible for securing what is in the cloud, using techniques like least privilege, which is illustrated above in the example IAN authorisation image.

3.3 Virtual Private Cloud (VPC)

The VPC provides the network infrastructure and an additional layer of security for the system. It protects the contents and enables them to communicate with the Internet. There are numerous configurations and micro services that can be utilized in the VPC. The following micro services were configured for use in the GP-VPC.

3.3.1 VPC Components

Micro Service	**Function**
Application Load Balancer:	traffic is directed to healthy instances
Auto Scaling Group:	adjust capacity to meet demand
NAT Gateway:	enable instances in a private subnet to connect to the internet
Internet Gateway:	allows communication between instances in the VPC and the internet
Subnets:	private and public range of IP addresses
Route Table:	Specify how network traffic is directed inside the VPC
Network Interface:	web server a public IP address
Security Groups:	control inbound and outbound traffic for the instances
Network ACL's	control inbound and specify deny for outbound traffic for subnets
Flow Logs:	Capture the traffic that flows in the VPC
Endpoints	privately connect to a VPC

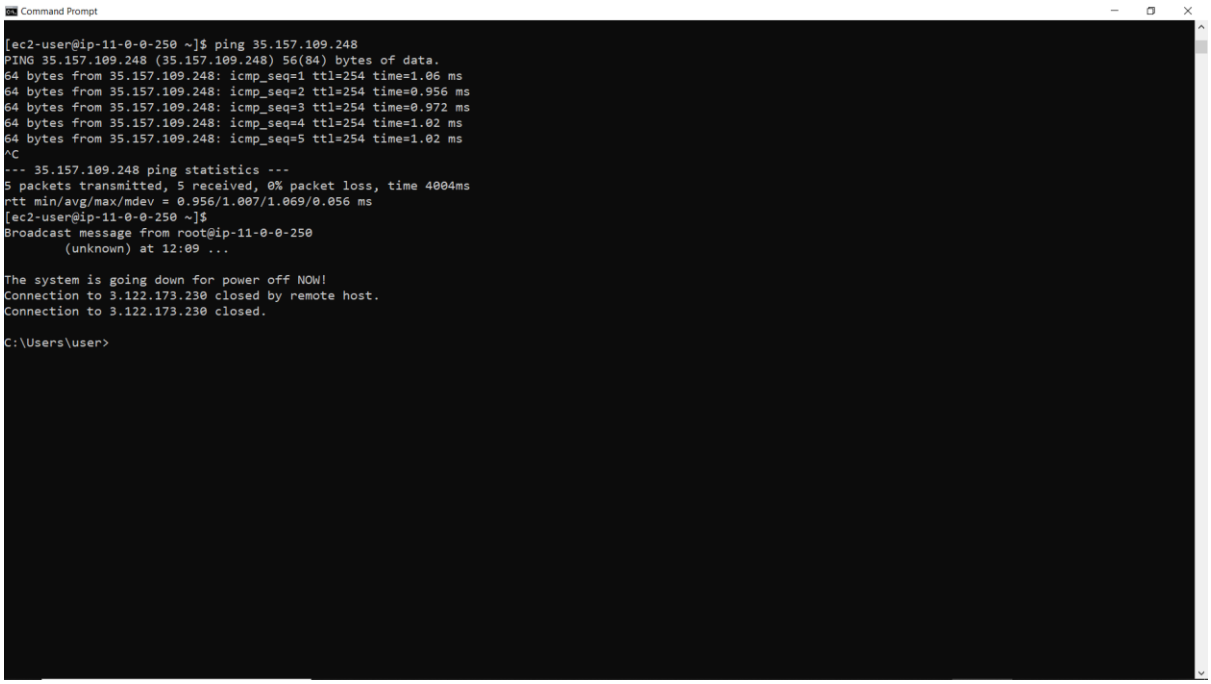
It is important to distinguish between ACL's and Security groups, which both play an important role in securing the subnets and instances within the GP-VPC. Another important component is the NAT Gateway it is responsible for connecting the private subnets with the Internet. It is interesting to note that AWS charge 52p an hour for a NAT Gateway that is not in attached to an instance Indeed, the instance would not likely cost that much if it were left to run. Flow logs should also be mentioned as they are used, along with other data capture techniques, to aggregate data, and share it with other services such as Security Hub and CloudWatch.

The application load balancer and auto scaling groups ae discussed in more detail later in this report. A detailed table listing all the components of the VPC is available in Appendix E.

3.3.2 VPC Peering

In order for the GP to use the VPC to communicate with other GP's or NHS staff a peering connection was created. Peering allows one VPC to communicate with another as if they were instances in the same VPC. This means that if every GP in the country had a VPC, their systems would be able to communicate with each other. The image below demonstrates the VPC Peering Connection, where a ping is sent by one VPC, and received by another. Test documentation in Appendix A, section 1.3

Peering connection



There are numerous types of configurations and scenarios in which VPC Peering can be of business value. The image above illustrates a one to one connection; however a one to multiple connections would be required for the GP to successfully benefit from the service. For example, if the NHS database could communicate with the GP-VPC database then the results of all the tests taken could be instantly aggregated and analysed. The benefits of having test results from each GP in the country delivered to the NHS in real time, for analysis and research are clear and numerous.

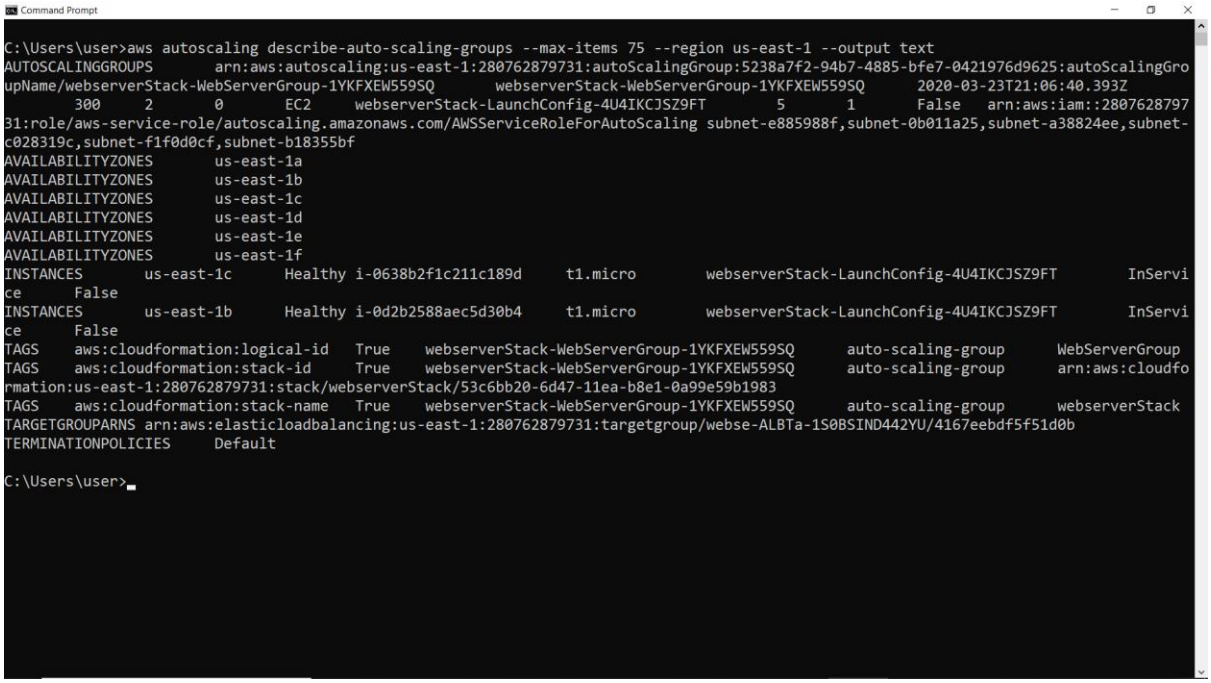
There are also various types of connection available using AWS, which should be investigated for future development. These include;

- Transit Gateway
- Direct Connect
- Virtual Private Networks (VPN)

3.4 Elastic Compute Cloud (EC2)

The EC2 Instance was configured as a web server to interface with the database, the script used in this configuration can be found in Appendix C. section 3.2. The website is a resource, where virus updates and best practices for health can be organised and shared to millions in seconds. A detailed description of the configuration and development is documented in Appendix A. section 1.3. The image below is the output from an aws cli command, listing auto scaling groups.

aws autoscaling describe-auto-scaling-groups



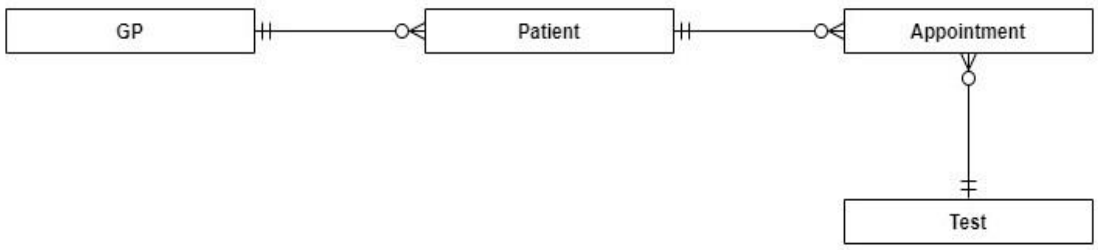
3.5 Relational Database Service (RDS)

EC2 may also be configured to host a relational database. This option was considered and rejected based on performance; RDS is faster, and fault tolerance: RDS includes the option to deploy across multiple availability zones (Multi -AZ). A comprehensive comparison was published by NetApp (2017), which states that RDS, *"provides high availability and failover support for DB instances with Multi-AZ deployments. Multi-AZ deployments for MySQL use Amazon technology, while a hosted Amazon EC2 MySQL database you can use partial replication, Global Transaction Identifier replication, or traditional statement-based replication".* The publication goes on to discuss the pricing options. The EC2 hosted database is less expensive, however with the additional benefits of fault tolerance and performance, RDS is better value for money.

Although RDS provides its own security, IAM can be configured to provide access to users, adding an additional layer of security and flexibility. All data is encrypted while at rest in the RDS automatically. RDS features also include CloudWatch Logs, which can be generated and used for security analysis, snapshots are taken for back up and disaster recovery and being a fully managed service means less hassle for the GP to ensure patches are up to date and security measures are compliant.

To demonstrate how the RDS, in the GP-VPC could be used, to add business value, a database was designed and based around the need for testing in the country. It is important to test so that the spread of the virus can be tracked. The ERD in Appendix B. section 2.2 illustrates the database design and the image below is an extract from the GP-ERD. A detailed description of the development, deployment and configuration can be found in Appendix A section 1.3.

GP-ERD



The GPDB select statement below is a query written for the database. The query gathers data from all four tables and prints the result. The name of the GP, and patients that tested true for the virus, contact details, age, appointment date and test result. Running the query reveals two patients were found to have the virus. The GP can immediately contact them to arrange treatment.

The above statement provides another example why RDS was chosen to manage the data stored by the GP. A Relational Database Management System (RDMS) is designed to manage complex queries. The full SQL statement for the database can be found in Appendix B.

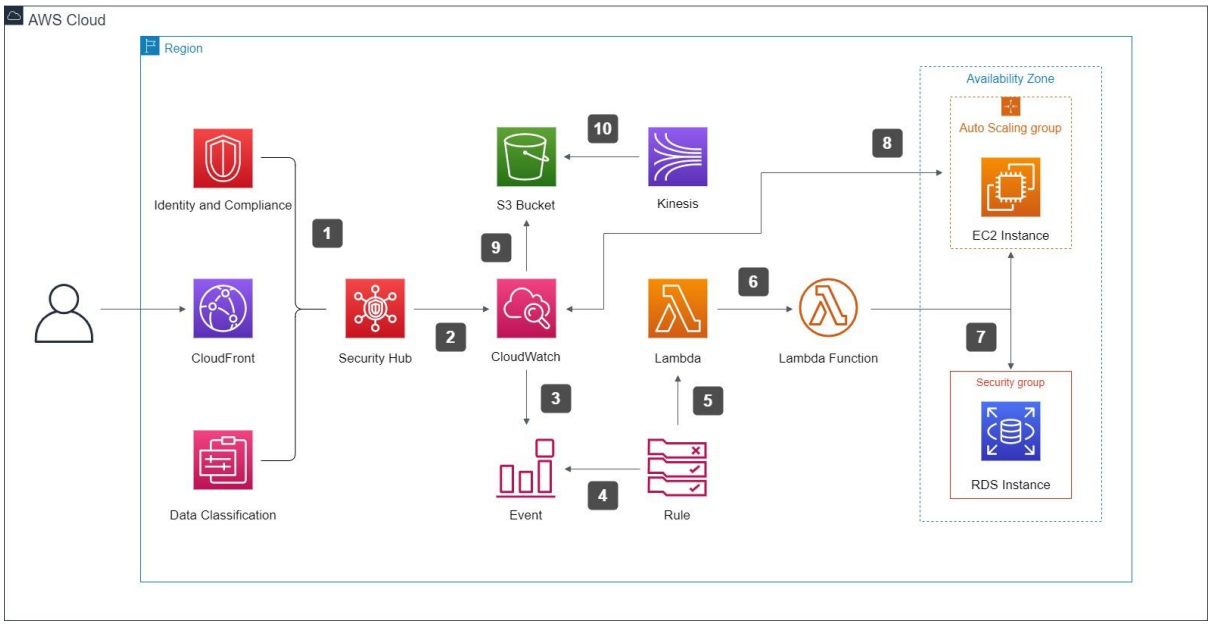
GPDB Select Statement

```
SELECT IF (result, 'true', 'false') result, DATE_FORMAT(appointmentDate,'%y-%m-%d') as
'Appointment Date', patient.name as Patient, patient.phone as Contact, YEAR(CURDATE())-
YEAR(dob) as Age, gp.name as GP
FROM test, appointment, patient, gp
WHERE (test.testID=appointment.testID AND patient.patientID=appointment.patientID) AND
(result=true) AND (gp.gpid=patient.gpid);
```

3.6 Monitor and Respond Overview

The diagram below details how the monitor and respond section of our GP-VP, is architected. The diagram also, provides an overview of the entire system and how the VPC integrates. The model was developed with the well architected framework as a guide. For example, automation is an operational excellence objective and monitoring is a performance principle. Indeed security, reliability and cost are all considered in the design and functionality of the system. A full screen view of this architecture is available in Appendix A section 1.2

Cloud Architecture Overview



Monitor and Respond

1. Identity and Compliance, Data Classification and CloudFront metrics sent to the Security Hub
2. The findings are sent to CloudWatch where
3. An event is triggered
4. A rule (for example, unauthorised access)
5. That triggers Lambda
6. Lambda invokes the function
7. The function takes action to neutralise the threat

Performance and Reliability

8. Health Checks and Auto Scaling

Analyse and Learn

9. CloudWatch sends logs to a bucket
10. Kinesis analyses logs in the bucket

AWS (2016) recommend centralised security as best practice, Security Hub meets that objective. Along with some of the other security services, like Macie and Inspector, IAM Access Analyser is integrated with Security Hub. GuardDuty, which actively monitors the VPC and ensures against DDoS attacks, is also included in the Hub. The management and governance icon refers to the data classification and compliance structures inherited from the industry. The data, classification and compliance are processed in the Security Hub and findings shared with CloudWatch.

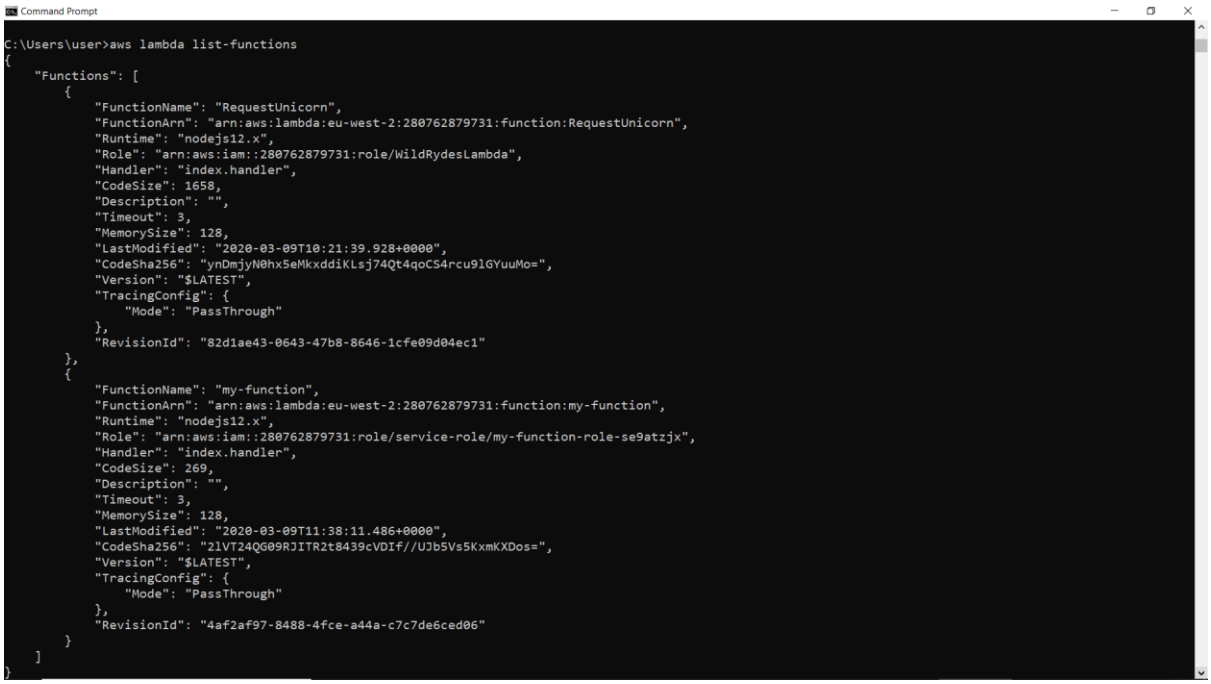
3.6.1 CloudWatch

CloudWatch is a powerful service it is integrated with almost everything AWS and works in conjunction with CloudTrail to ensure all actions a user makes are recorded. CloudWatch processes log files to determine if any rules were broken. If an event is triggered by the data classification rules, then Lambda is invoked and the system responds with an action. Otherwise, the logs are sent to an S3 Bucket and used to analyse and learn. CloudWatch also has a direct relationship with the auto scaling instance. It monitors health and makes adjustments accordingly.

3.6.2 Lambda

Once a security threat has been detected and the Lambda function is invoked the action could be stopping the instance and starting another. Indeed Lambda functionality is able to perform almost any task required from system maintenance to managing the entire system. Evolving with the system and responding to system events are operational excellence objectives.

List of lambda functions via AWS CLI



4 Critical Analysis

The AWS cloud has many advantages however; the cost management interface and pricing structure seem to be deliberately inefficient and complicated. For an entrepreneur to set up and manage a system they will need to spend a significant portion of their time managing costs. Many of the costs are hidden or even misleading.

The GP-VPC system is robust, reliable and fault tolerant, however, the system should be implemented using a server less architecture. This could drastically reduce costs and time managing the system. On the other hand, the setting up the server less system could be more complicated.

5 Conclusion

AWS provide a first class, cost effective and fault tolerant platform to launch, monitor and manage services. Almost everything is integrated, and if its not currently, it most likely will be soon. The pricing and cost management tools are important to understand and utilise, as the value of operating in the cloud is dependent on cost, along with security, availability and fault tolerance.

CloudFormation provides a valuable service that allows developers and administrators to manage deploy and document the services provisioned efficiently and accurately. It manages Elastic Beanstalk and Lightsail applications, making it an extremely powerful tool. With CloudFormation a single line of code can start an entire empire.

CloudWatch and CloudTrail allow customers to track, monitor and notify. The logs generated can be used for security, marketing, or to improve the existing system, by analysing patterns and making design decisions based on learning.

Combining these services with a VPC gives business owners and developers the opportunity to use infrastructure worth billion, for pennies a week. The VPC acts as the foundation for secure, reliable, efficient, compute power or data storage.. Although complicated in technological terms, in real terms the VPC is simple. Cloud Computing technologies such as virtualisation and advancements in Data Center design and structure ensure services like the VPC will only gain in popularity.

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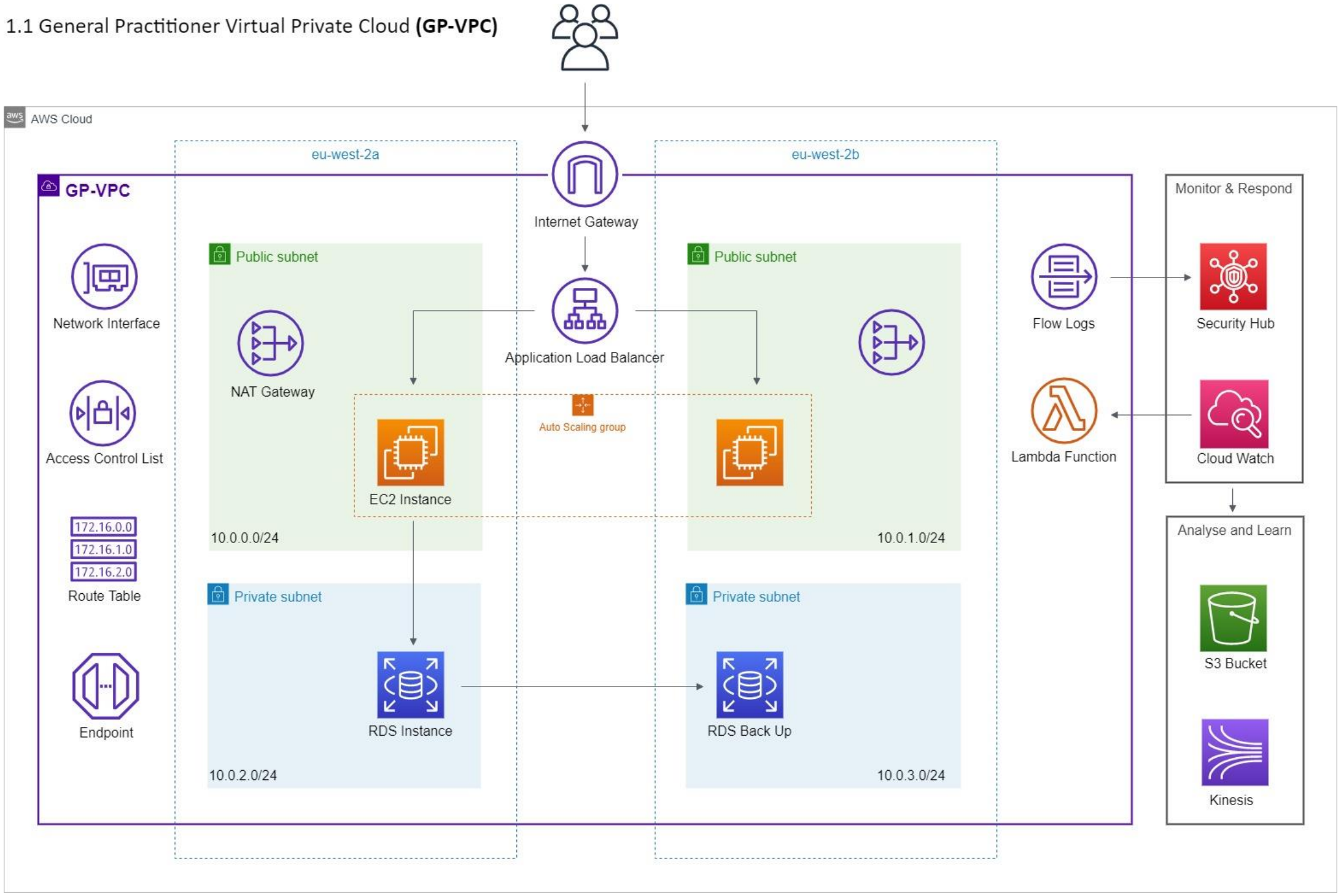
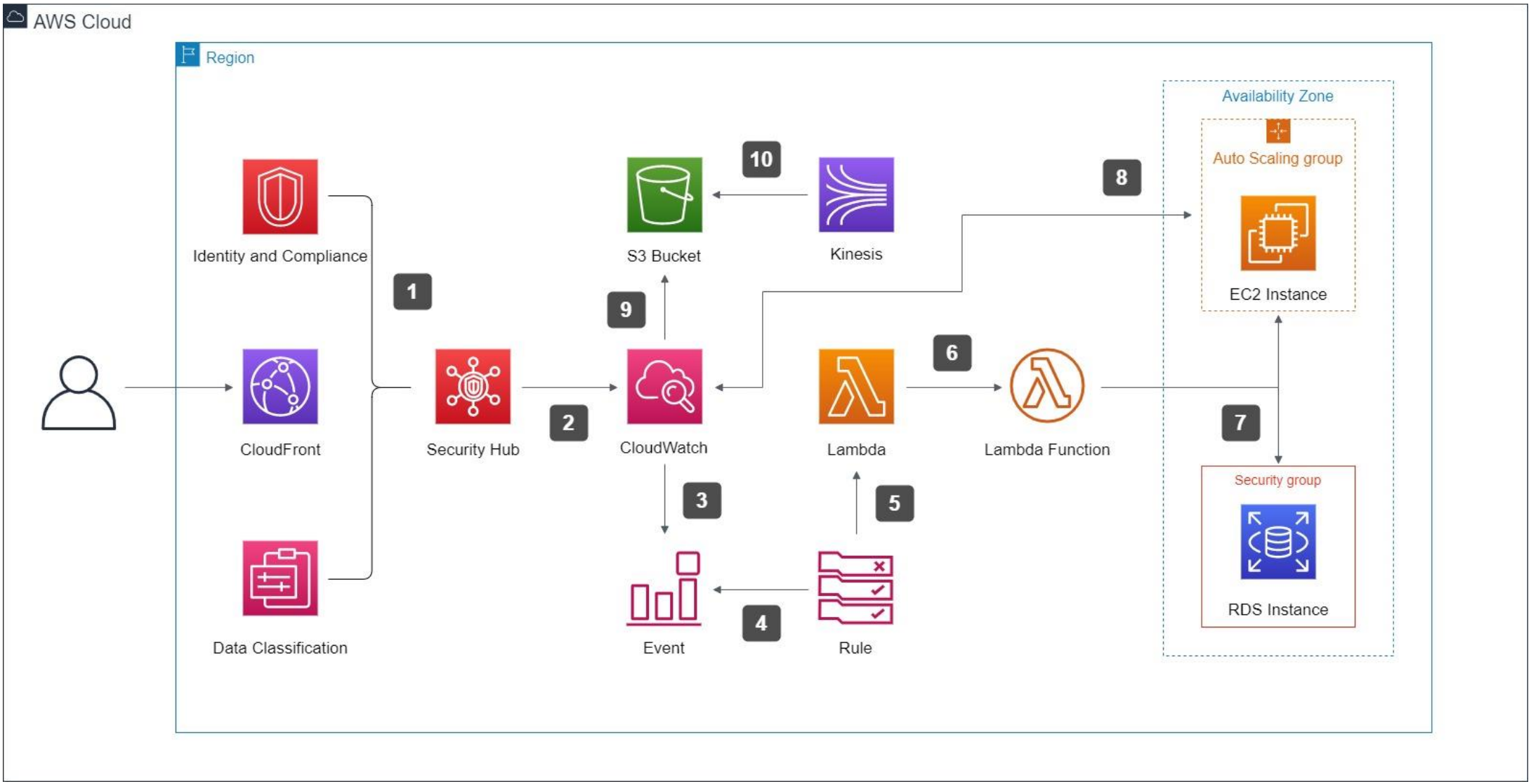
Appendix A

1.1 General Practitioner Virtual Private Cloud **(GP-VPC)**



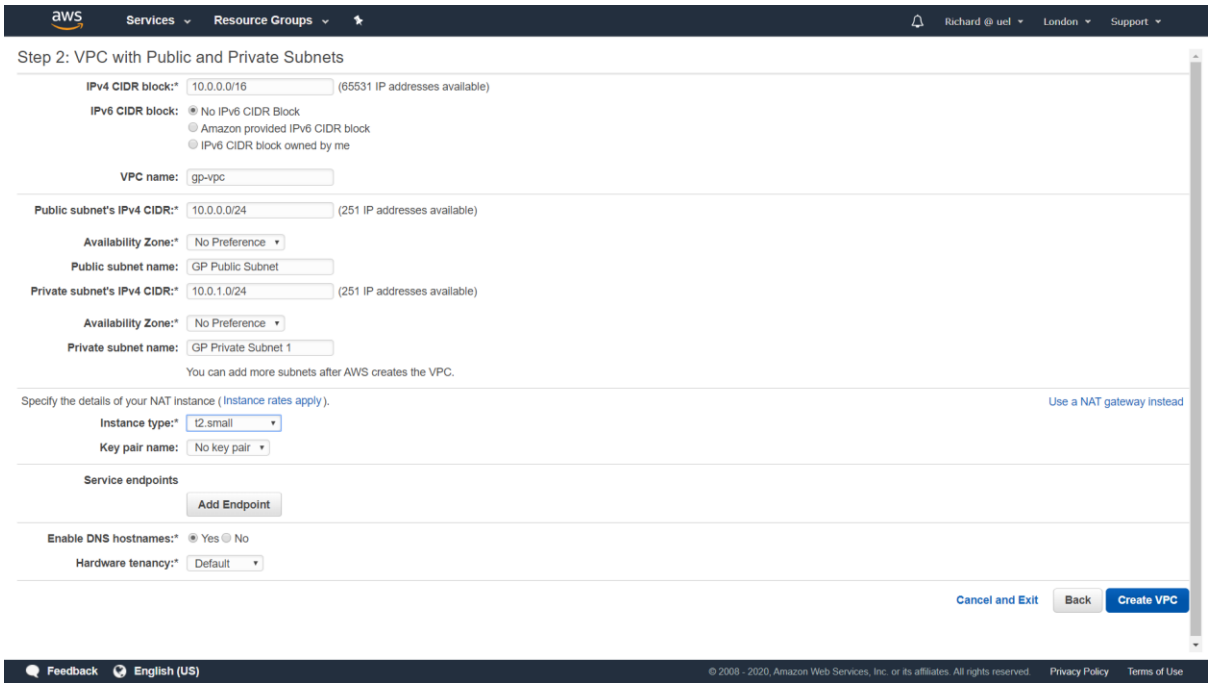
1.2 Monitor and Respond - System Overview



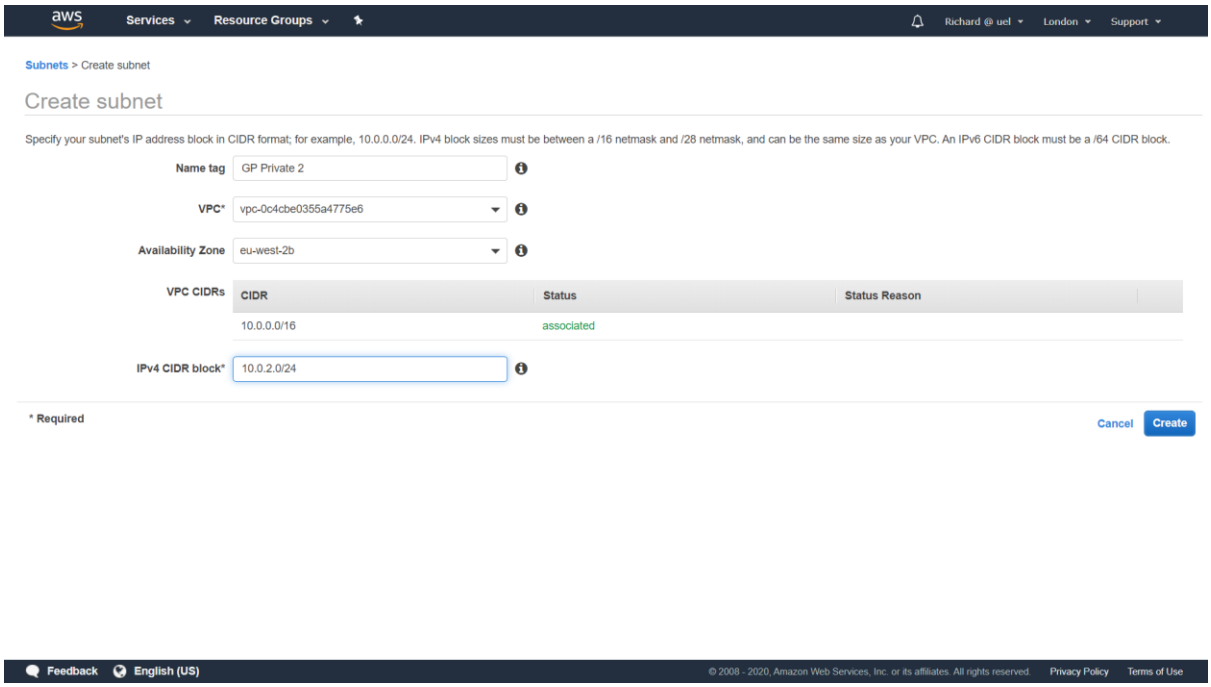
1.3 Console Development

As recommended by the AWS well architected framework, at least two subnets are required, one to be public facing and one private. The public facing subnet will be used as a web server, and the private subnet used to add an additional layer of security for the secure database.

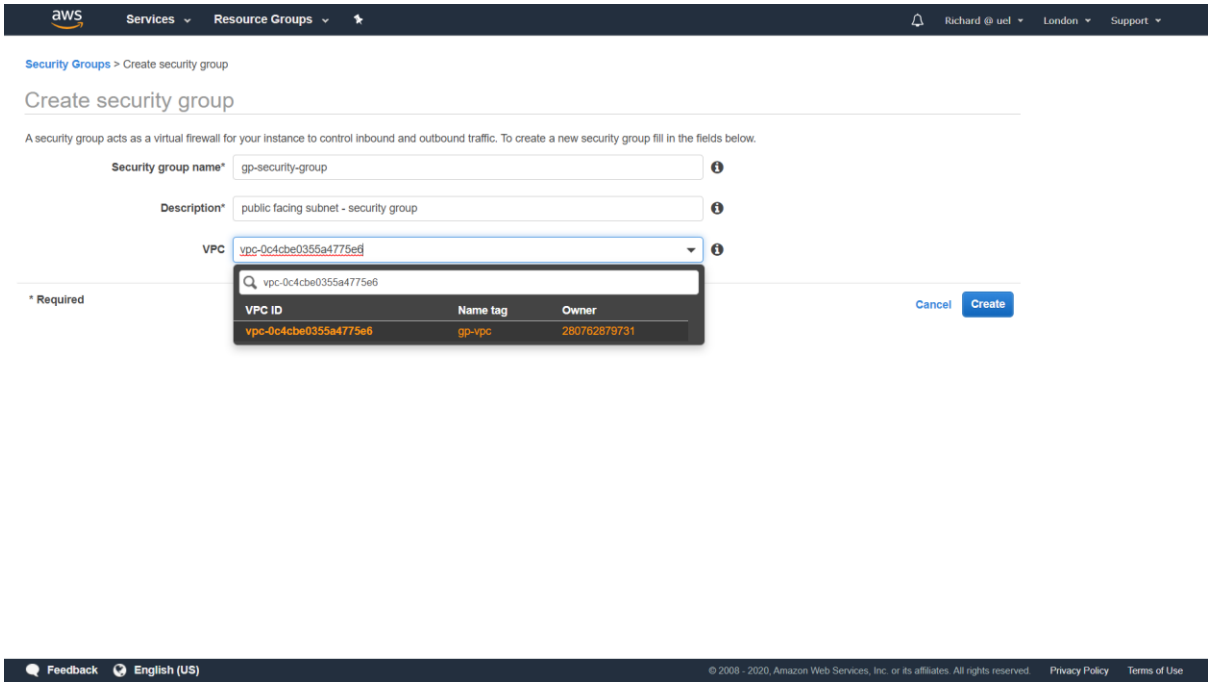
1. Create a VPC configuration - vpc-0c4cbe0355a4775e6



2. Create additional Subnet – subnet-03dbc15e016449caa

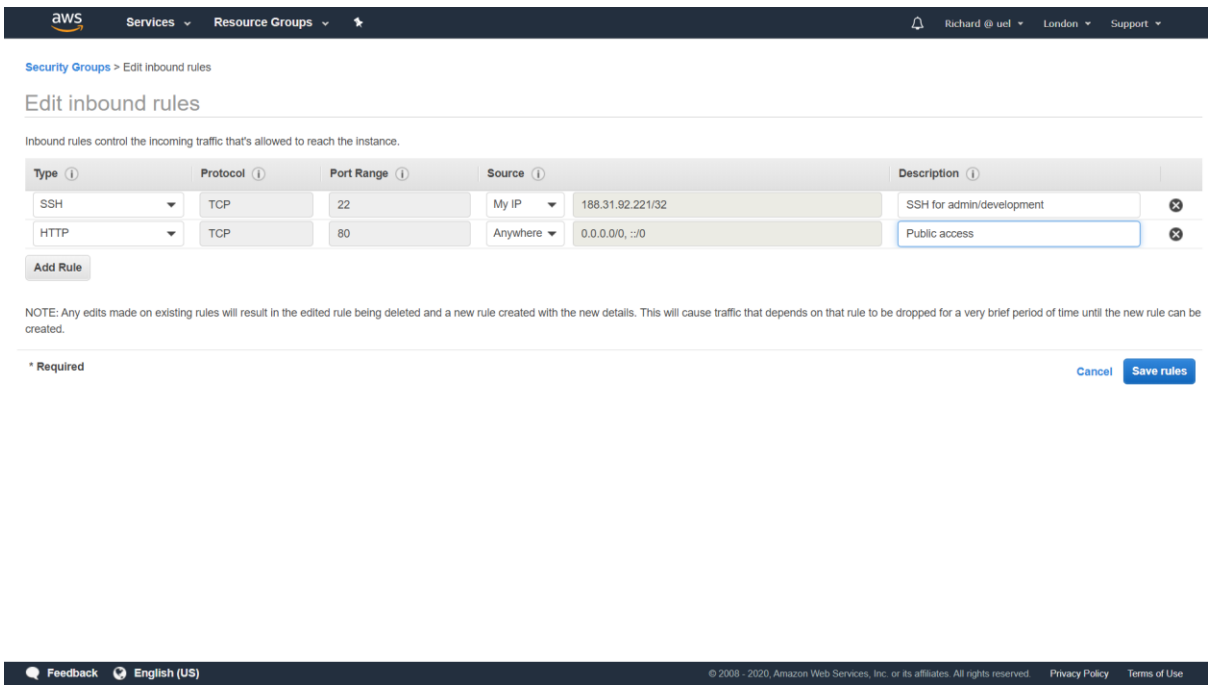


3. Create Security Groups for public and private subnets - sg-0c195f869438b803c

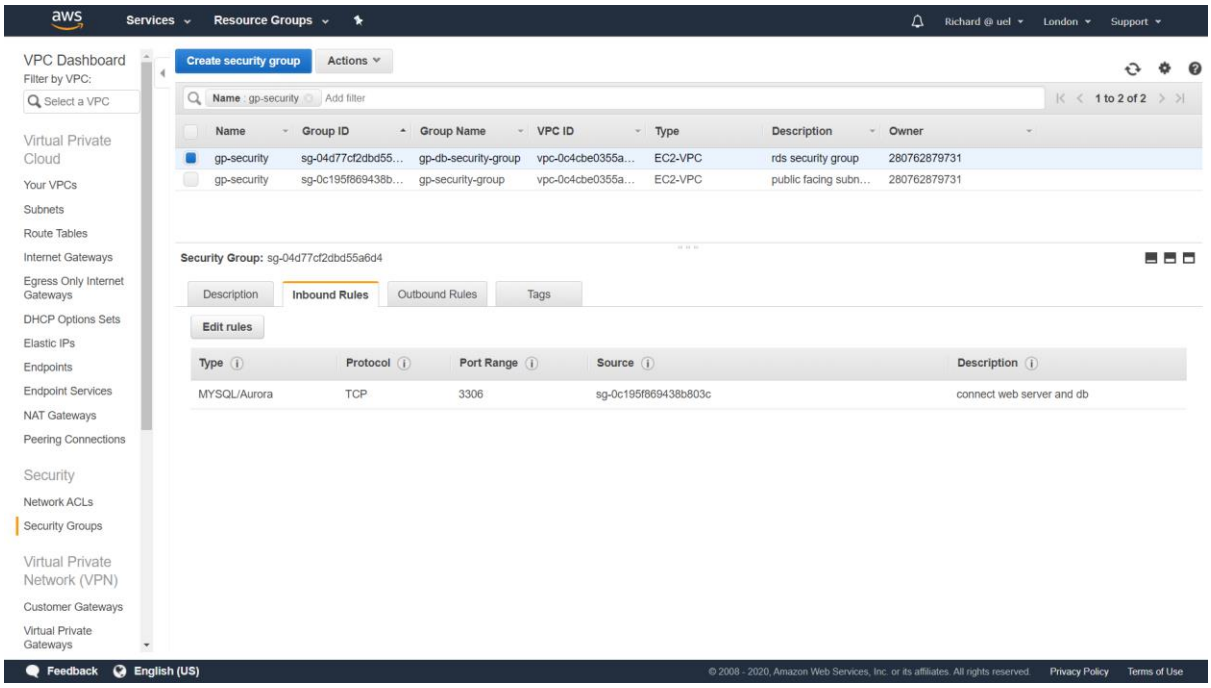


The security groups are required by default. However, they do add an additional layer of security. For example, the private security group can be configured to only allow inbound traffic from the EC2 instance. This means that any would be hacker that access the EC2 instance would still not gain access to the data.

4. Create Inbound rules for SSH access



5. Create Private subnet

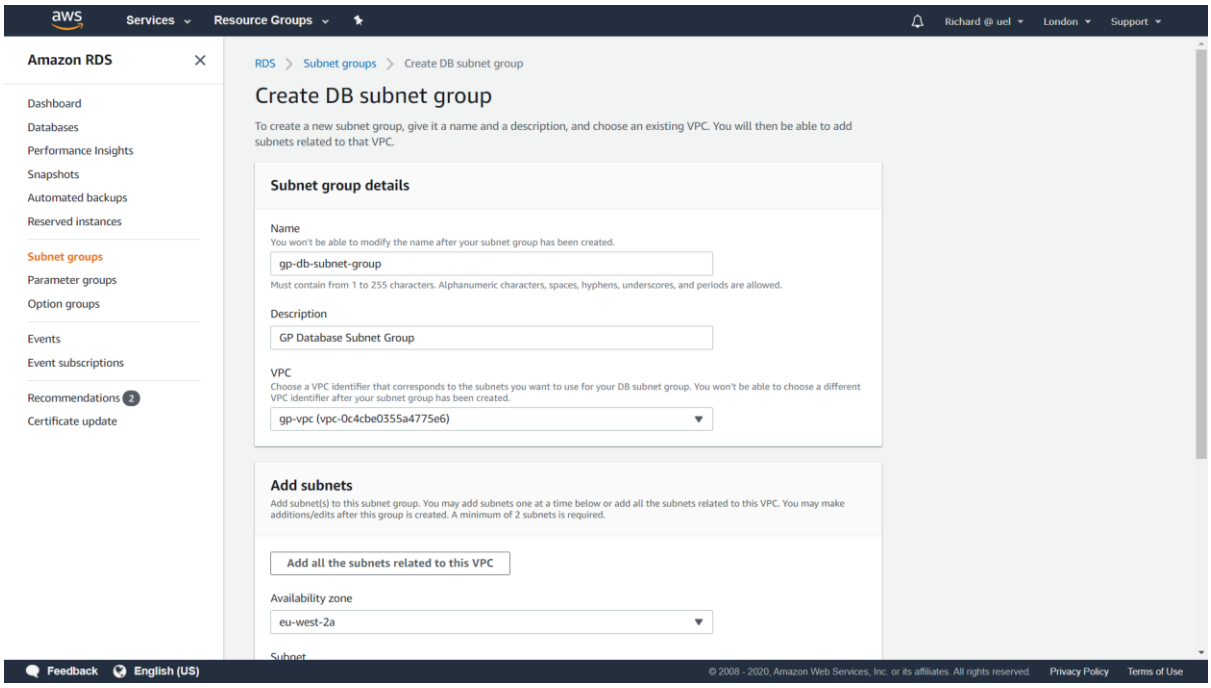


Create the Database

RDS endpoint: *gp-db.cpyoaulck67v.eu-west-2.rds.amazonaws.com*

The endpoints are used to connect to the database. The endpoint could be public or private. In this case the endpoint is private. The data stored by the GP must be protected at every layer.

6. Create DB Subnet



7. Complete the configuration

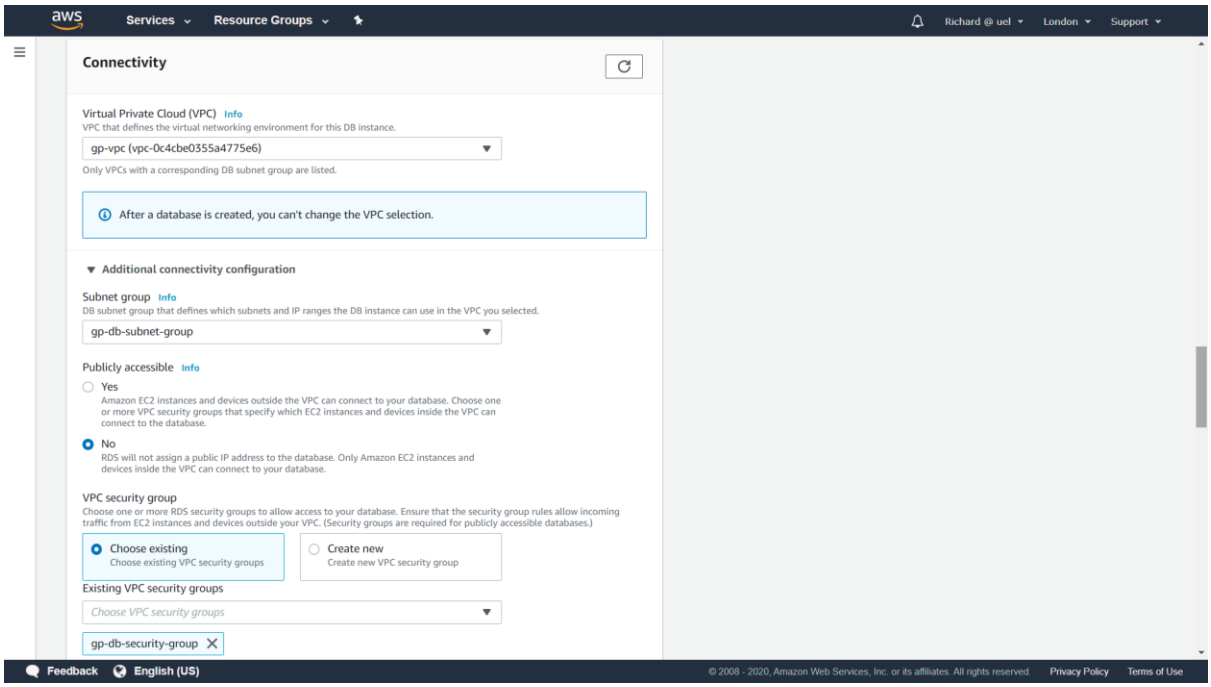
The configurations set on this page a critical to the performance and reliability of the database. Indeed the costs and security pillars should not be overlooked. It is important to understand each configuration option.

On this page users can configure IAM groups that have access to the data, decide where and how to store log files and ensure the database is deployed across multiple availability zones,

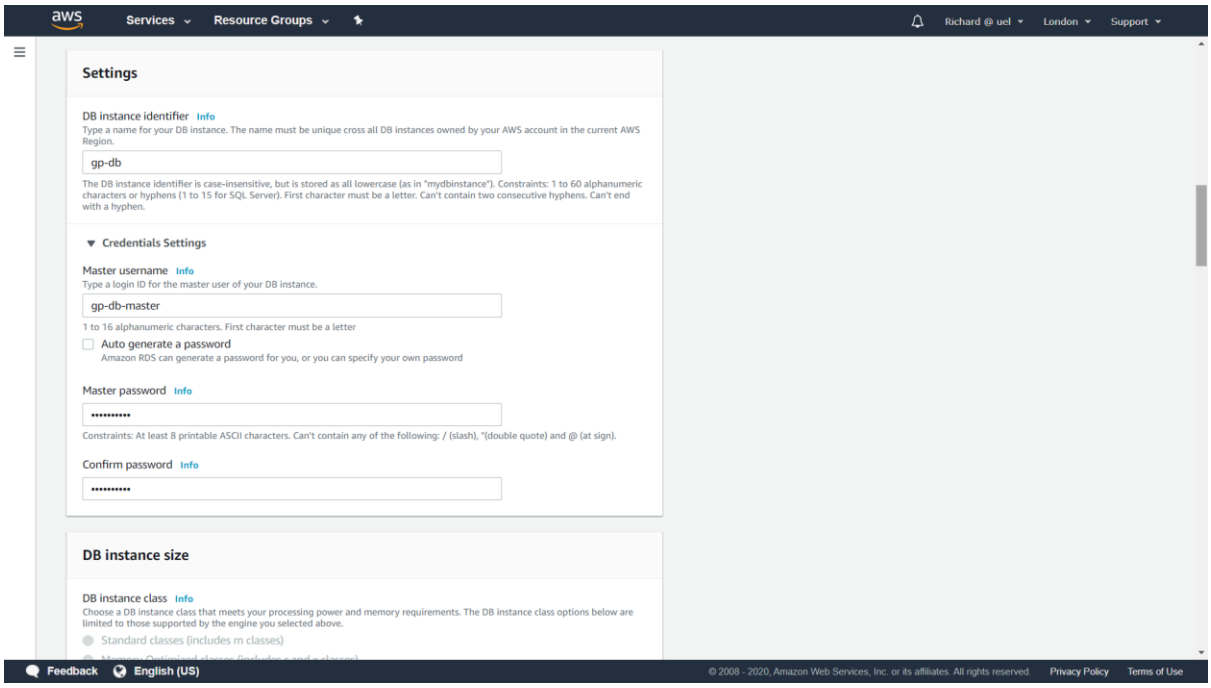
a. Subnet group - gp-db-subnet-group
b. Add VPC Security group
c. Add Subnets
d. Publicly accessible – NO
   RDS will not assign a public IP address to the database. Only Amazon EC2 instances and devices inside the VPC can connect to your database.
e. Choose one or more RDS security groups to allow access to your database. Ensure that the security group rules allow incoming traffic from EC2 instances and devices outside your VPC.
f. Amazon EC2 instances and devices outside the VPC can connect to your database. Choose one or more VPC security groups that specify which EC2 instances and devices inside the VPC can connect to the database.
   Choose

g. IAM role
h. Deletion protection
i. Maintenance
j. Backup
k. Monitoring
l. Log exports – to CloudWatch

RDS Configuration

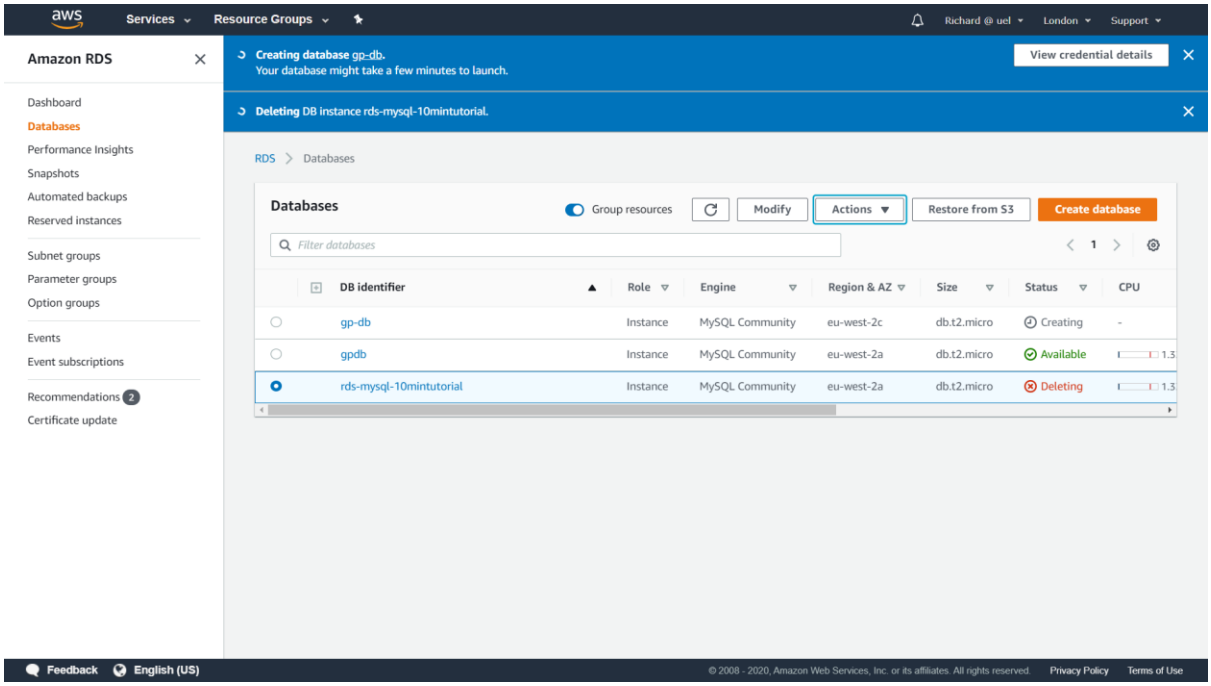


8. Complete the settings



Once the database is created, the EC2 instance that will be configured to serve the content can be provisioned. There are numerous options to do this, however the next section details the stages using the management console

9. The database is created

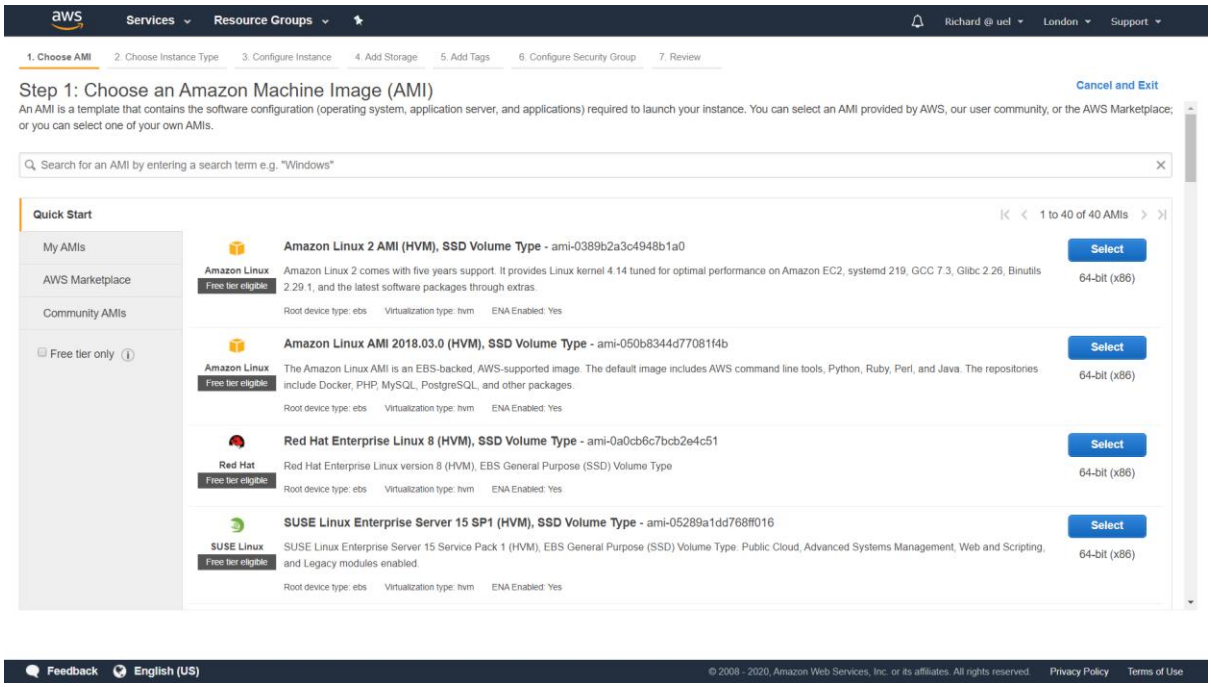


Appendix A section 1.4 documents the process of creating an instance using CloudFormation.

Create EC2 instance and install web server

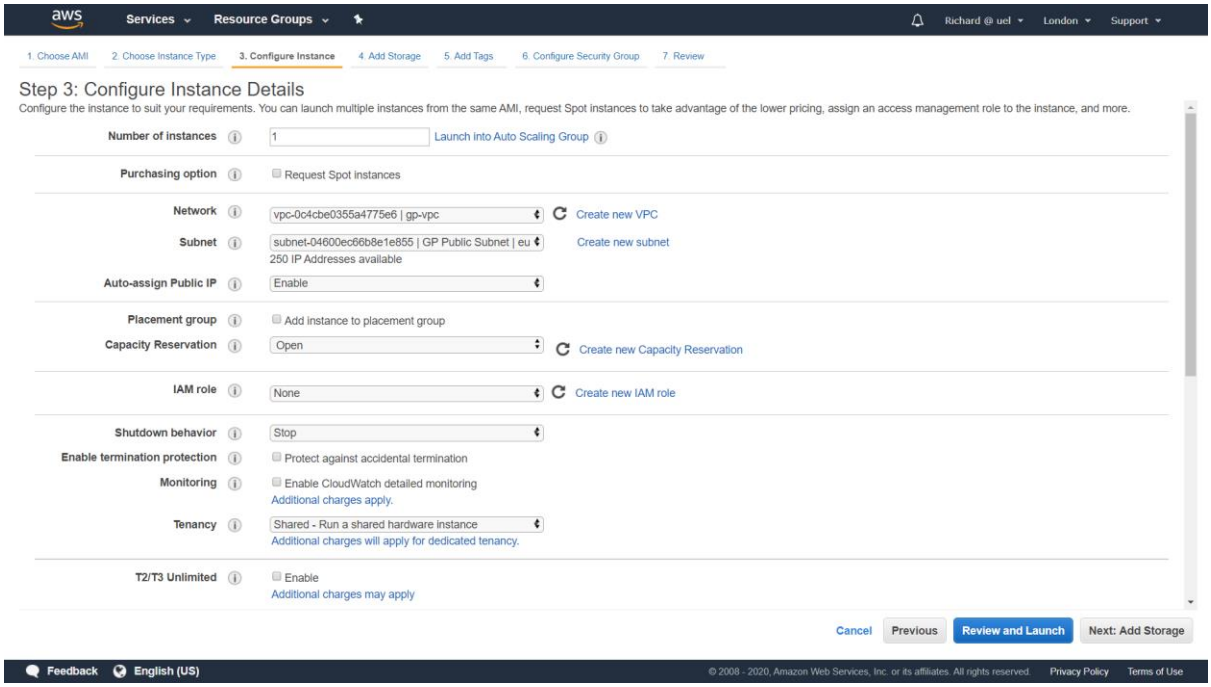
Instance id: - *i-00c6ca195e3f92dd3*

1. Chose AMI

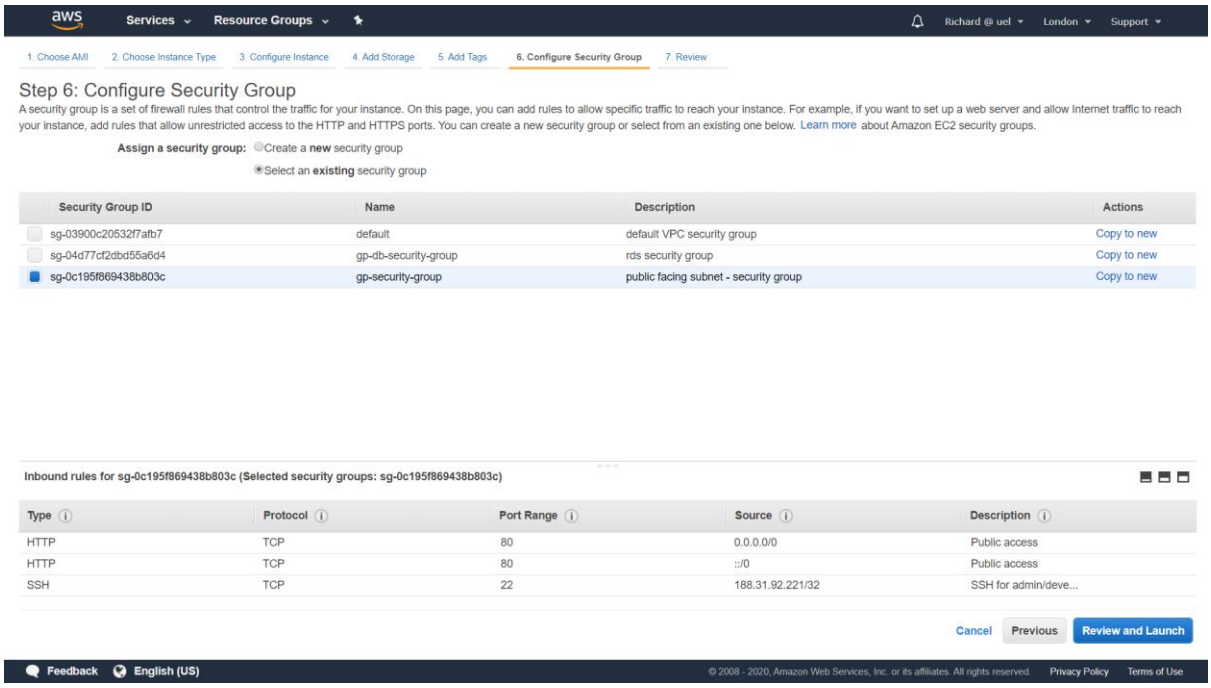


The configurations on this page are critical to the performance of the system. This example uses a micro instance to demonstrate the process.

2. Configure the instance



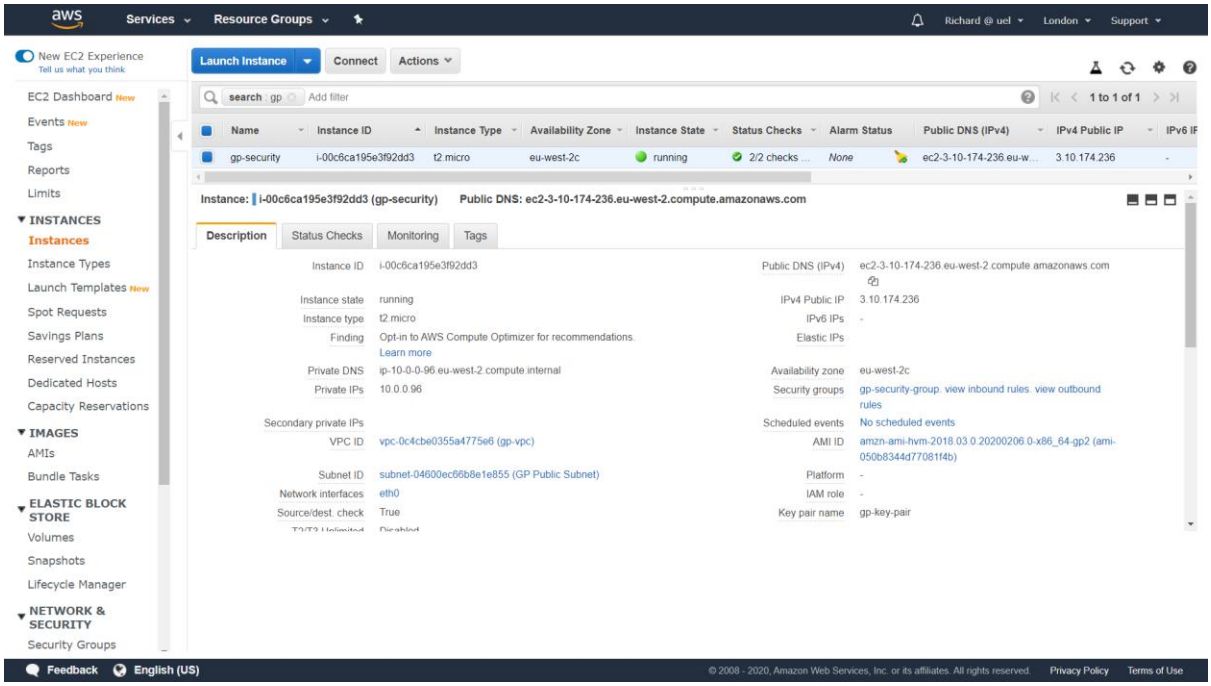
3. Configure Security groups



These security groups will be used to access the database. The only access to the database will be via the security groups configured on this page.

For the purpose of this test an additional inbound rule was added allowing the developer to access the database using a private connection

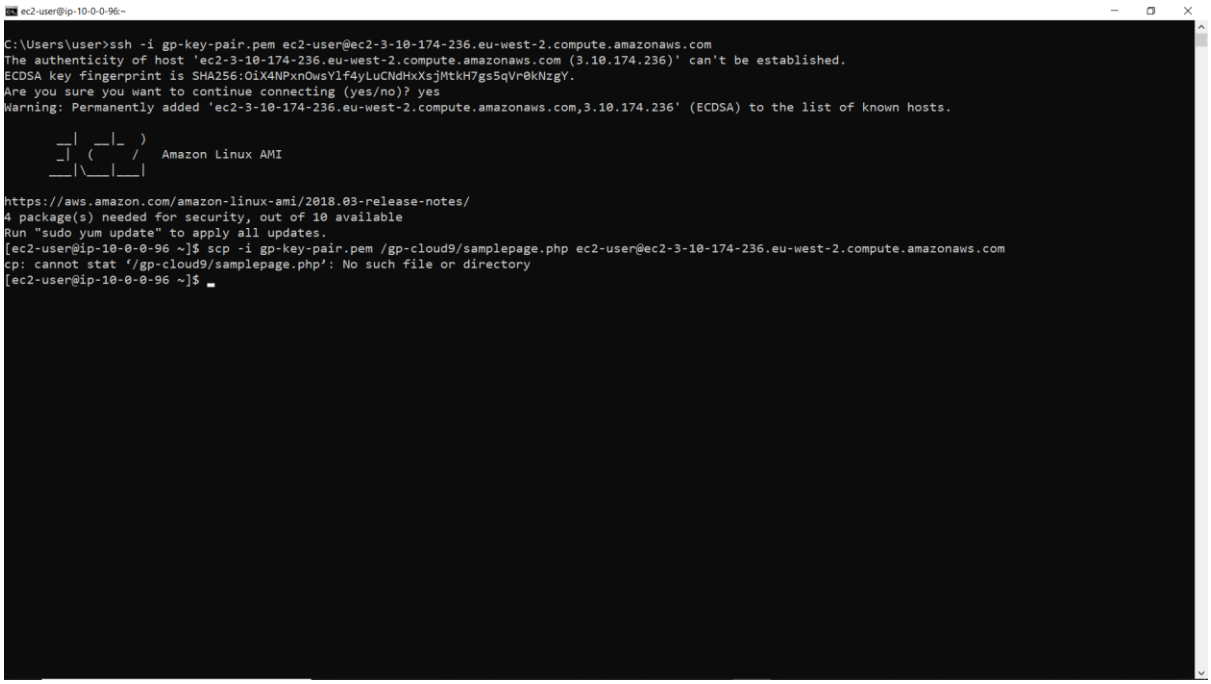
4. After completing the configuration the instance is created



5. Connect to the instance

Connection string used to connect to the EC2 instance:

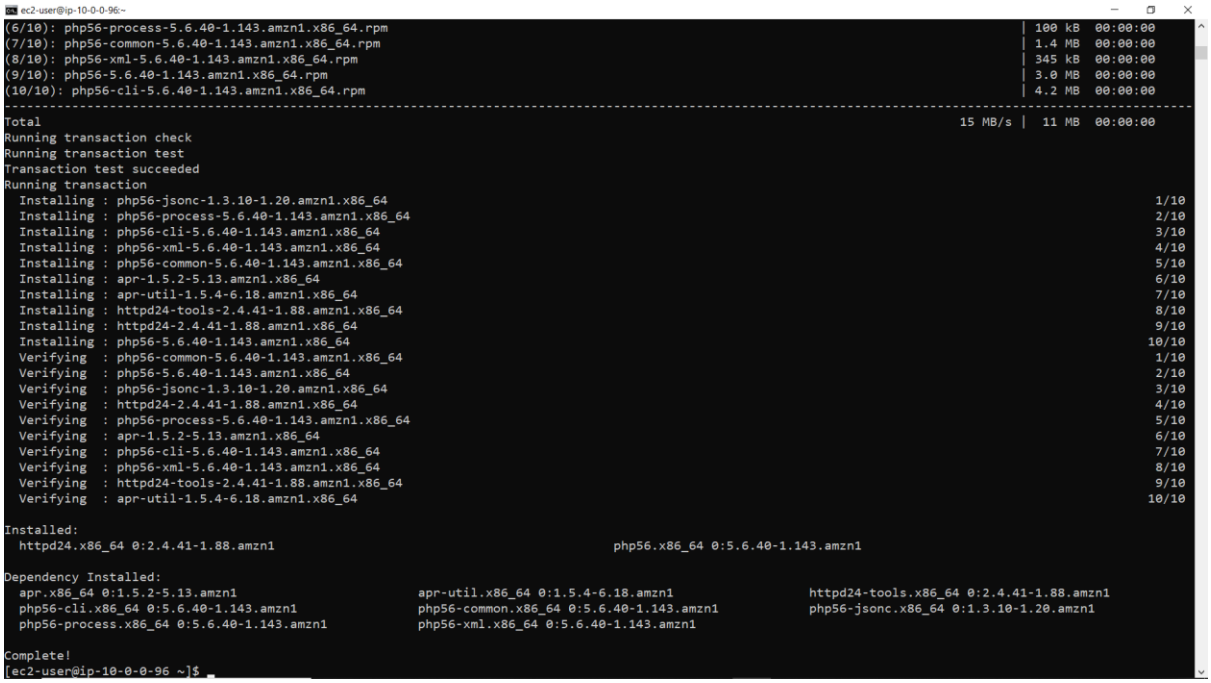
- *ssh -i gp-key-pair.pem ec2-user@ec2-3-10-174-236.eu-west-2.compute.amazonaws.com*



6. Update the server and Install the web server

Update and install syntax

- *sudo yum update –y*
- *sudo yum install –y httpd24 php56 php56-mysqld*



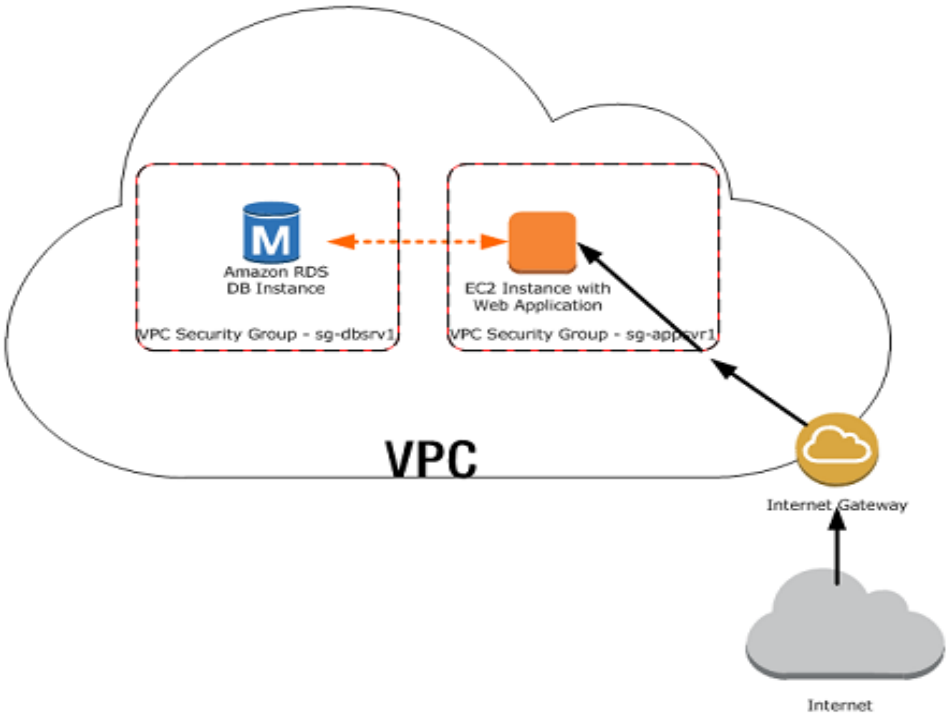
7. Start the server:

Start service syntax

- *sudo service httpd start*

```
ec2-user@ip-10-0-0-96:/var/www/html
Dependency Installed:
  apr.x86_64 0:1.5.2-5.13.amzn1                 apr-util.x86_64 0:1.5.4-6.18.amzn1              httpd24-tools.x86_64 0:2.4.41-1.88.amzn1
  php56-cli.x86_64 0:5.6.40-1.143.amzn1         php56-common.x86_64 0:5.6.40-1.143.amzn1        php56-jsonc.x86_64 0:1.3.10-1.20.amzn1
  php56-process.x86_64 0:5.6.40-1.143.amzn1     php56-xml.x86_64 0:5.6.40-1.143.amzn1

Complete!
[ec2-user@ip-10-0-0-96 ~]$ sudo service httpd start
Starting httpd:                                            [  OK  ]
[ec2-user@ip-10-0-0-96 ~]$ sudo chkconfig httpd on
[ec2-user@ip-10-0-0-96 ~]$ sudo groupadd www
[ec2-user@ip-10-0-0-96 ~]$ dir
[ec2-user@ip-10-0-0-96 ~]$ sudo usermod -a -G www ec2-user
[ec2-user@ip-10-0-0-96 ~]$ exit
logout
Connection to ec2-3-10-174-236.eu-west-2.compute.amazonaws.com closed.

C:\Users\user>ssh -i gp-key-pair.pem ec2-user@ec2-3-10-174-236.eu-west-2.compute.amazonaws.com
Last login: Sat Mar  7 15:36:05 2020 from 188.31.92.221.threembb.co.uk

       __|  __|_  )
       _|  (     /   Amazon Linux AMI
      ___|\___|___|

https://aws.amazon.com/amazon-linux-ami/2018.03-release-notes/
[ec2-user@ip-10-0-0-96 ~]$ groups
ec2-user wheel www
[ec2-user@ip-10-0-0-96 ~]$ sudo chgrp -R www /var/www
[ec2-user@ip-10-0-0-96 ~]$ sudo chmod 2775 /var/www
[ec2-user@ip-10-0-0-96 ~]$ find /var/www -type d -exec sudo chmod 2775 {} +
[ec2-user@ip-10-0-0-96 ~]$ find /var/www -type f -exec sudo chmod 0664 {} +
[ec2-user@ip-10-0-0-96 ~]$ cd /var/www
[ec2-user@ip-10-0-0-96 www]$ mkdir inc
[ec2-user@ip-10-0-0-96 www]$ cd inc
[ec2-user@ip-10-0-0-96 inc]$ >dbinfo.inc
[ec2-user@ip-10-0-0-96 inc]$ nano dbinfo.inc
[ec2-user@ip-10-0-0-96 inc]$ cd /var/www/html
[ec2-user@ip-10-0-0-96 html]$ >test.php
[ec2-user@ip-10-0-0-96 html]$ nano test.php
[ec2-user@ip-10-0-0-96 html]$ nano test.php
[ec2-user@ip-10-0-0-96 html]$ >samplepage.php
[ec2-user@ip-10-0-0-96 html]$ nano samplepage.php
[ec2-user@ip-10-0-0-96 html]$ [ec2-user@ip-10-0-0-96 html]$
```

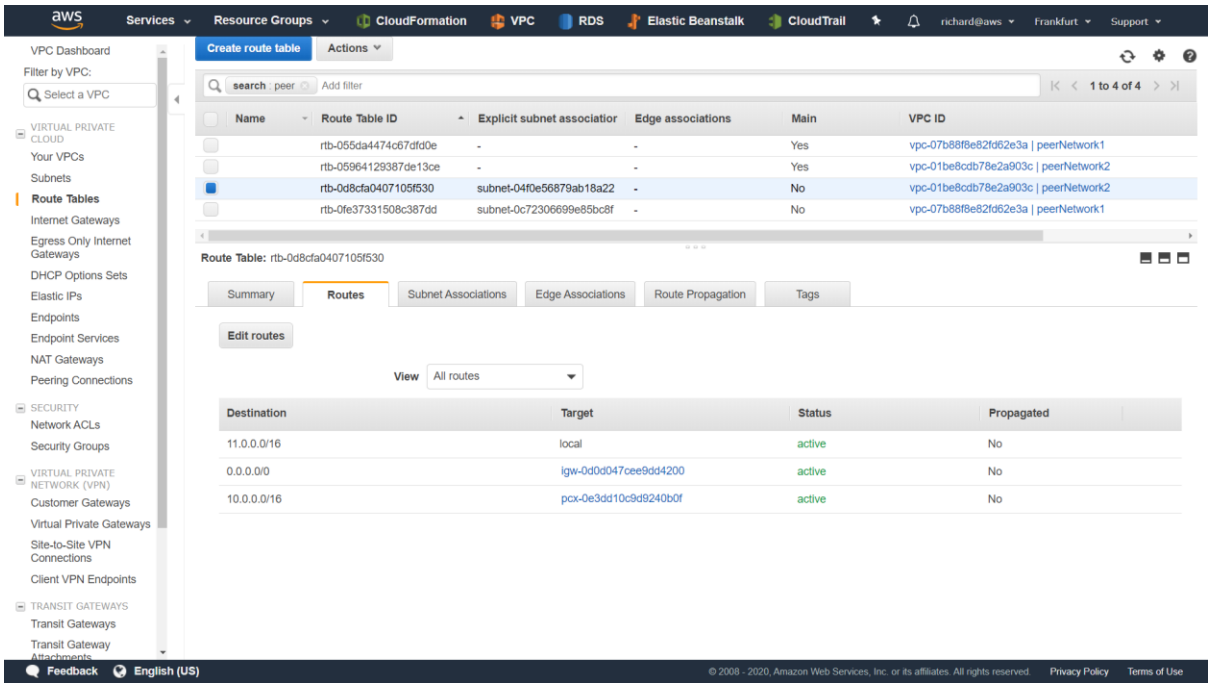
Virtual Private Cloud (VPC), Relational Database Service (RDS) and Elastic Compute (EC2)



https://docs.aws.amazon.com/AmazonRDS/latest/UserGuide/TUT_WebAppWithRDS.html

Peering

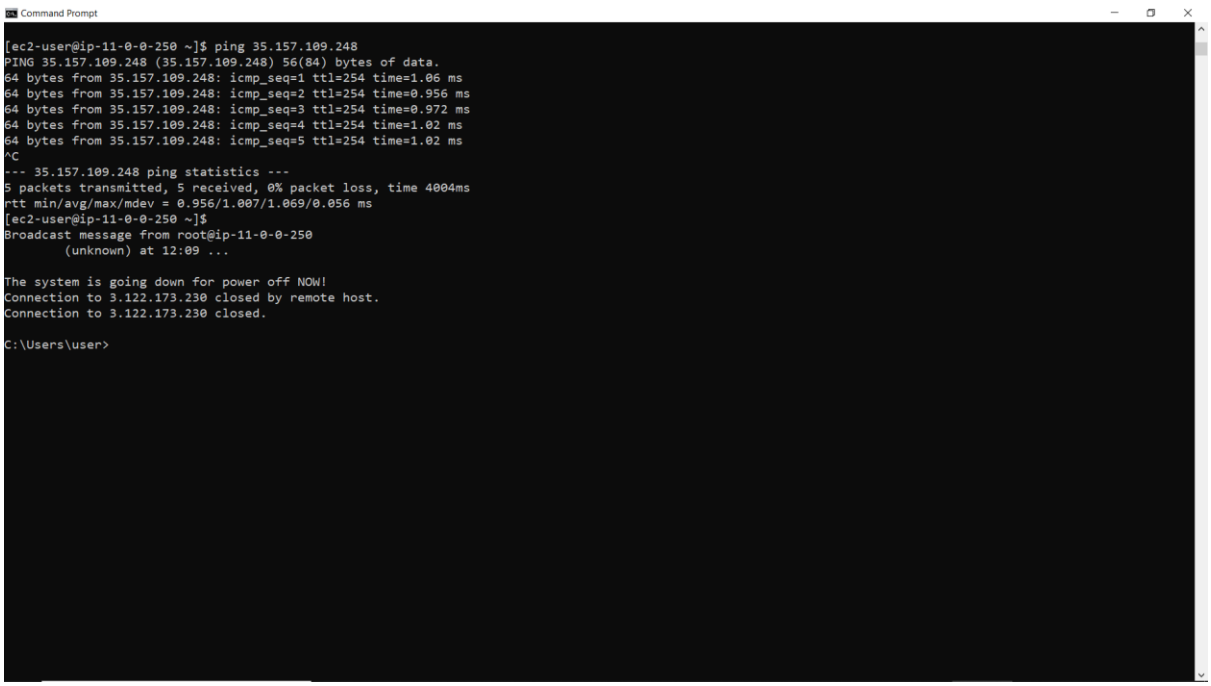
- Create 2 VPCs with different cidr blocks and verify internet gateways are present in both
- Create VPC peering connection, accept the request
- Edit route tables: add new route to the public subnets to the VPC connection **pcx** for VPCs



Create instances in both VPCs then edit the VPC security group to accept all ICMP

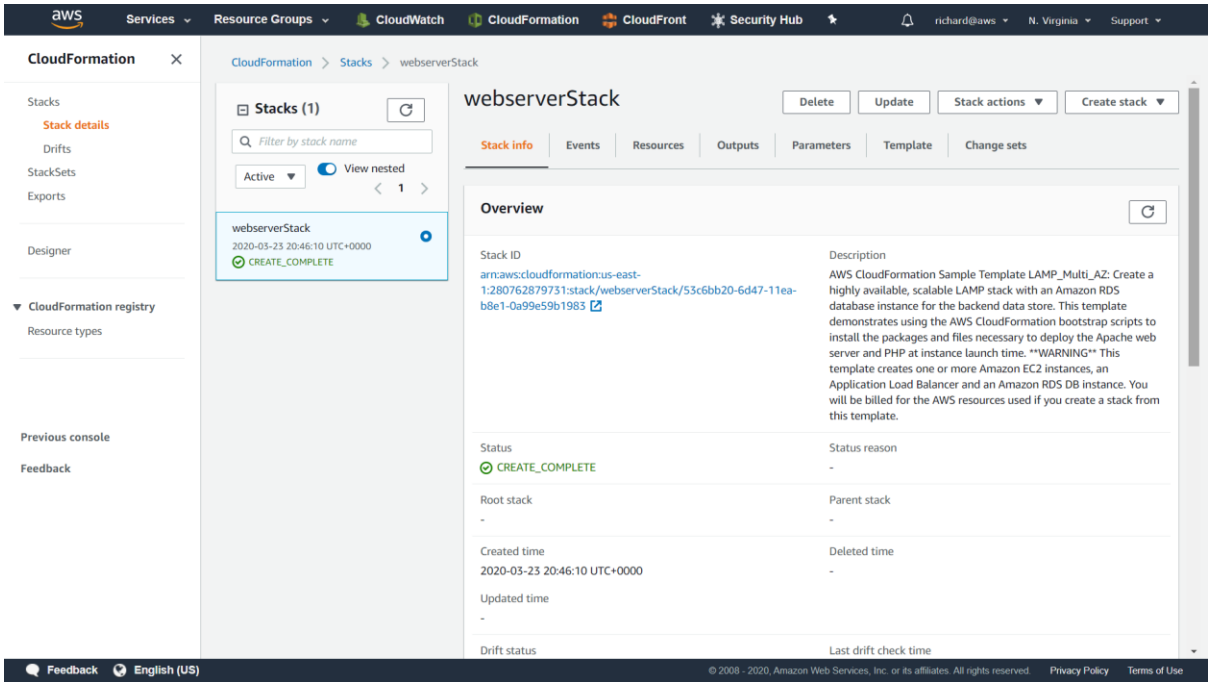
- *aws ec2 associate-address --instance-id i-0621ac048f4 --allocation-id eipalloc-04d999*
- *ssh -i peeringKeyPair.pem ec2-user@3.122.173.230*

Ping the server



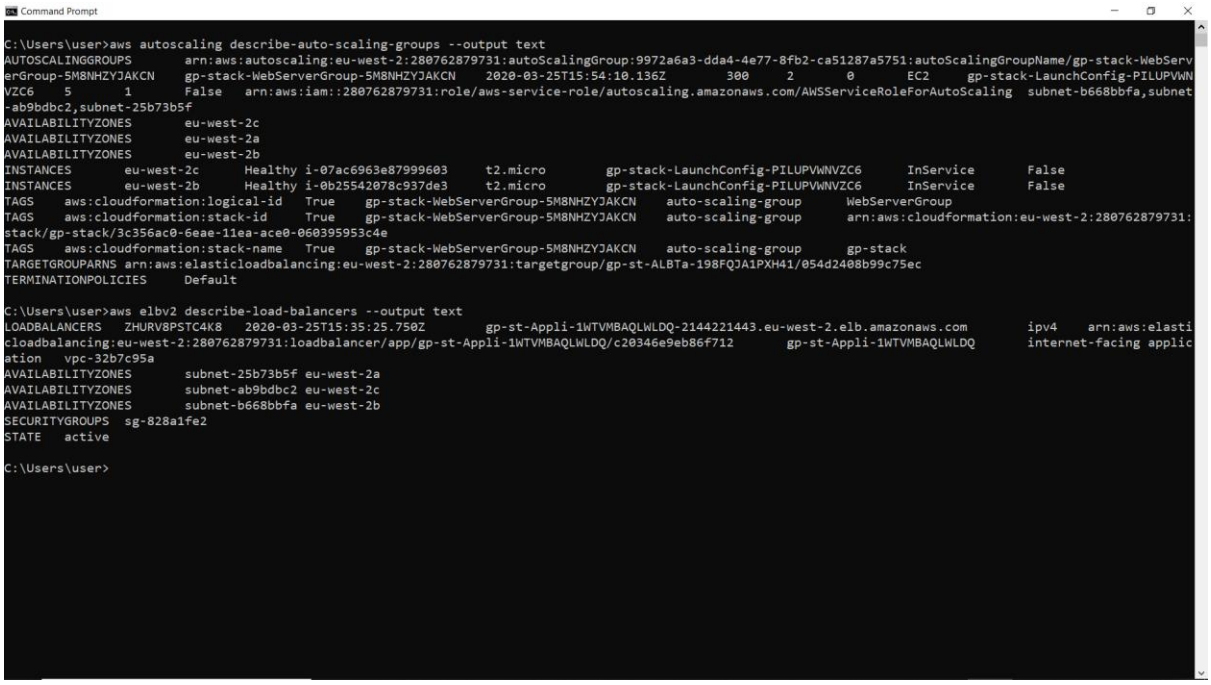
1.4 CloudFormation

Once the basic structure and contents of the system had been decided, CloudFormation was used to deploy the prototype application, and assist in the documentation of the project. . By using CloudFormation to complete the development users are able to see where improvements can be made and test them before implementing them in the live system.

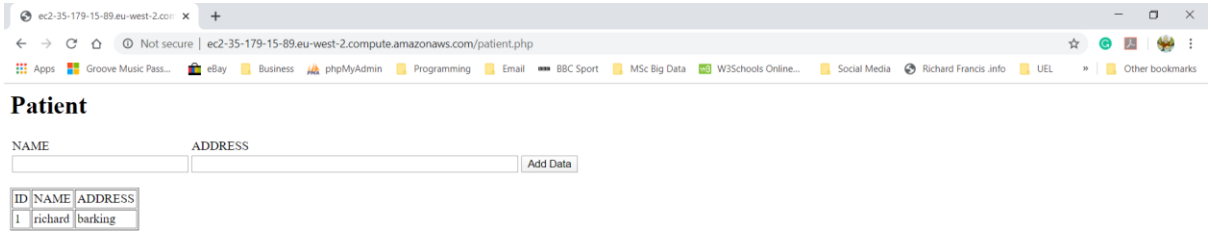


During the Cloud Development Process, two features of the system were not included, the Application Load balancer and the Auto Scaling Group. Both were included in the final template.

Auto Scaling and Application Load Balancer



Enter data using a browser

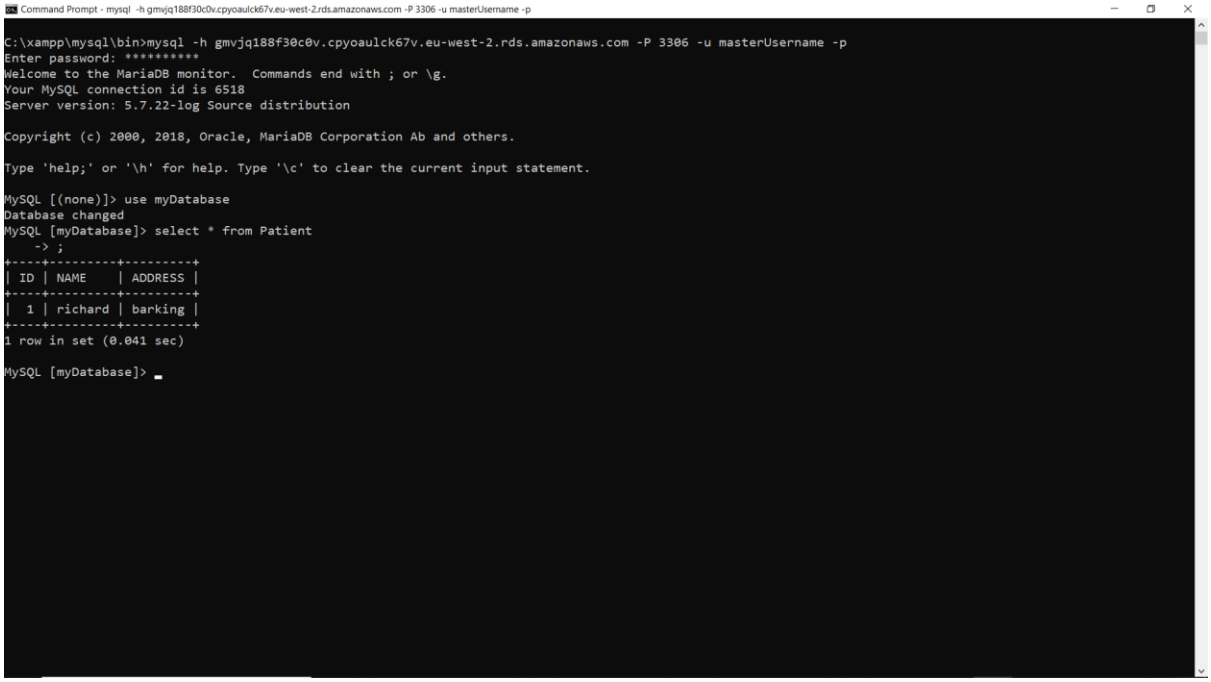


Once the stack has been created, simply configure, install and update.

Test the system works using a browser and enter data. The image below confirms that the data entered using a browser is the same as the user can see directly.

CloudFormation enable users to deploy applications much more efficiently. As an additional benefit the YAML syntax used by CloudFormation is very similar to English, so it acts as documentation for the system. An example of the YAML file is documented on the next page.

View the data using a direct connection



1.4.1 GP-STACK

Single line syntax used to deploy the stack

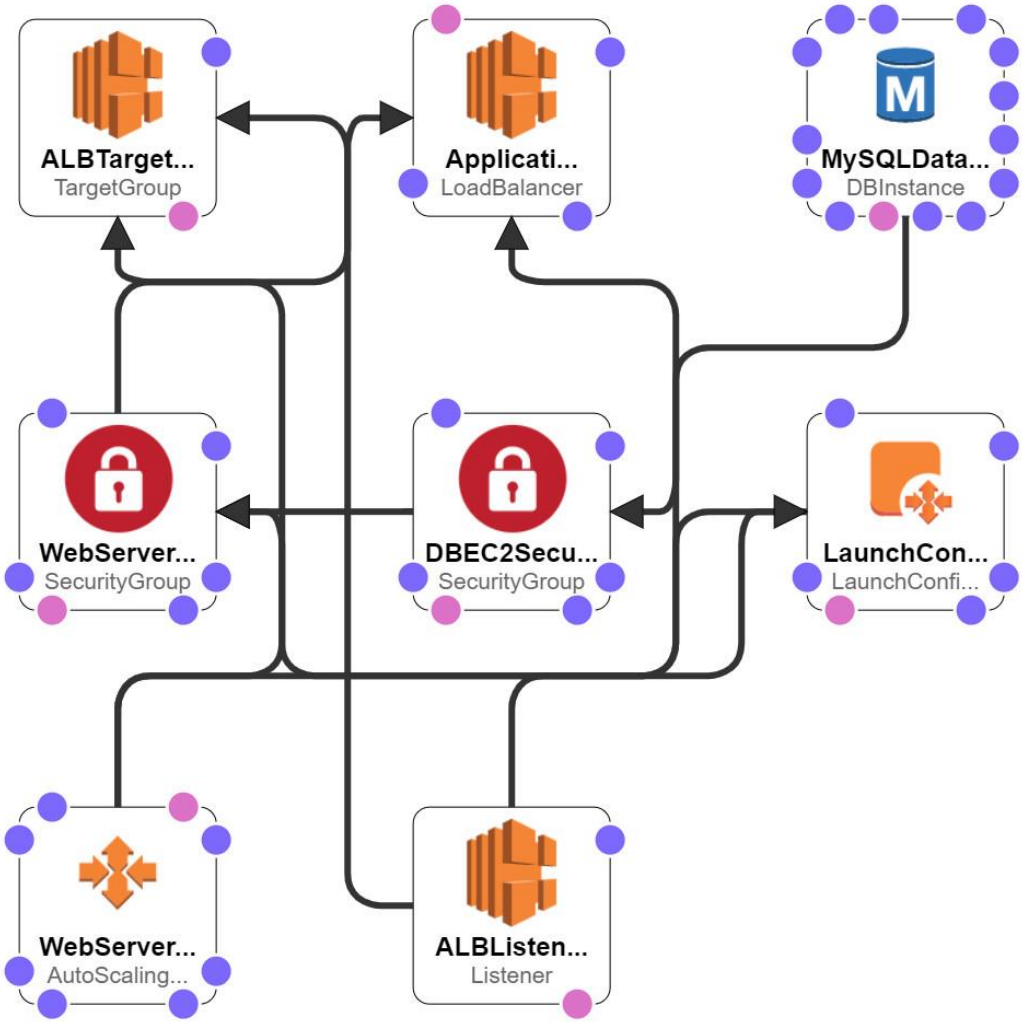
```
aws cloudformation deploy --template-file /CloudFormation/GP-STACK.yaml --stack-name gp- stack
```

GP-STACK. yaml

A copy of this template be downloaded here

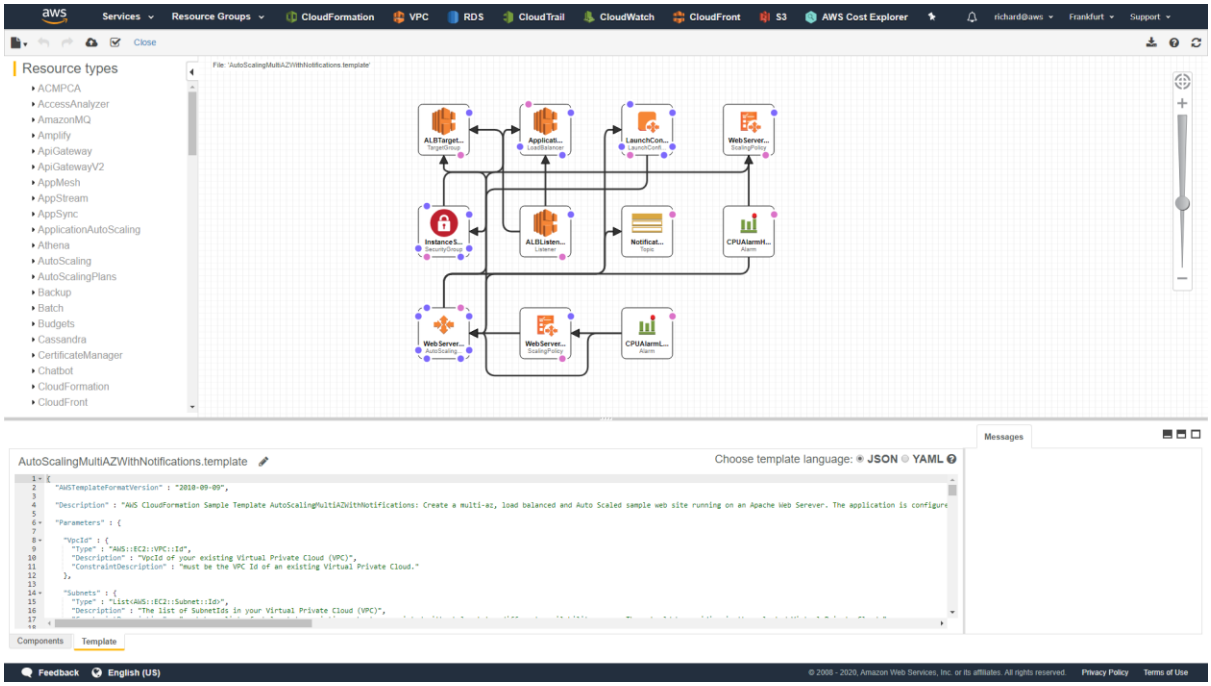
```
AWSTemplateFormatVersion: 2010-09-09
Description: >-
  AWS CloudFormation Template LAMP_Multi_AZ: Modified by Richard Francis for CN7026 - GP-VPC
Parameters:
  VpcId:
    Type: 'AWS::EC2::VPC::Id'
    Description: VpcId of your existing Virtual Private Cloud (VPC)
    ConstraintDescription: must be the VPC Id of an existing Virtual Private Cloud.
  Subnets:
    Type: 'List<AWS::EC2::Subnet::Id>'
    Description: The list of SubnetIds in your Virtual Private Cloud (VPC)
    ConstraintDescription: >-
      must be a list of at least two existing subnets associated with at least
      two different availability zones. They should be residing in the selected
      Virtual Private Cloud.
  KeyName:
    Description: Name of an existing EC2 KeyPair to enable SSH access to the instances
    Type: 'AWS::EC2::KeyPair::KeyName'
    ConstraintDescription: must be the name of an existing EC2 KeyPair.
  DBName:
    Default: gpdb
    Description: MySQL database name
```

1.4.2 GP-STACK.designer



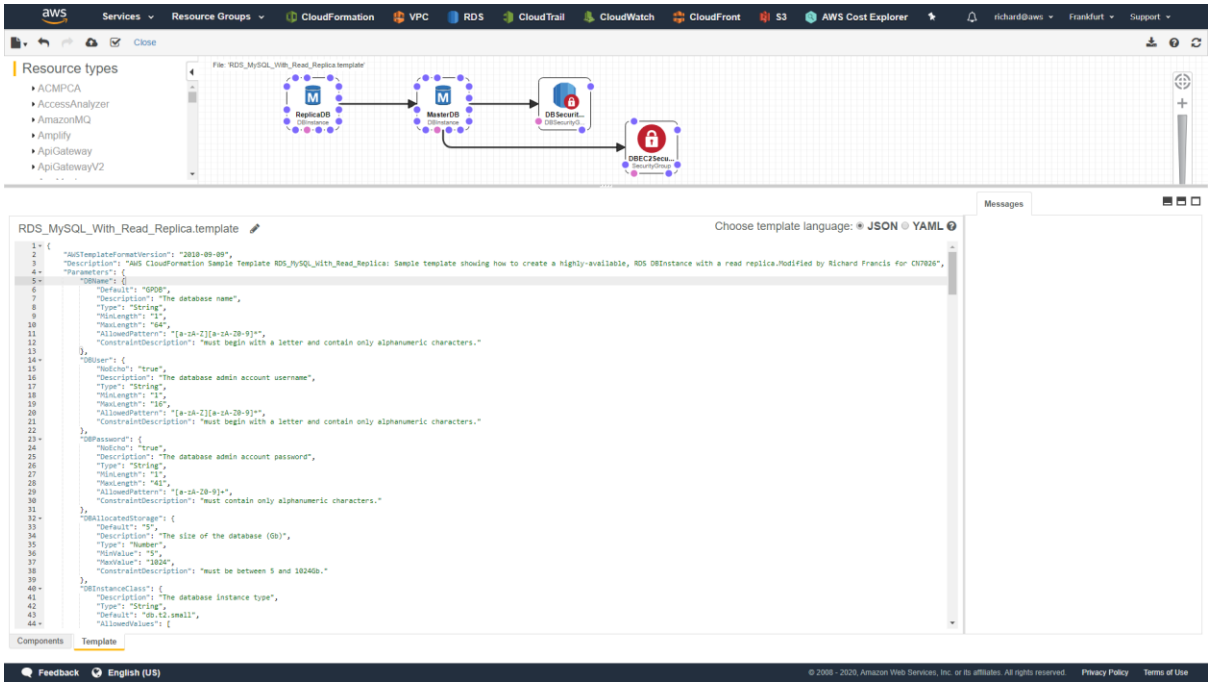
1.4.3 GP-STACK-SET

Auto Scaling, Load Balancing template with SNS notifications using CloudWatch alarms



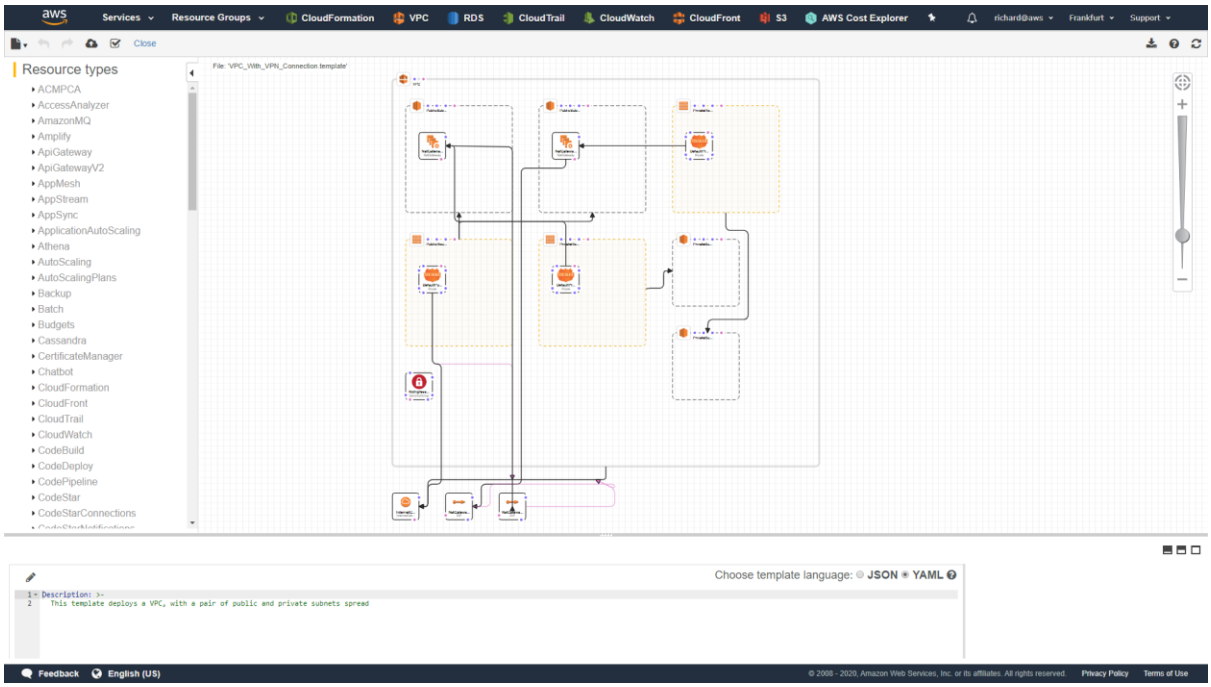
Download template

RDS MySQL with read replica



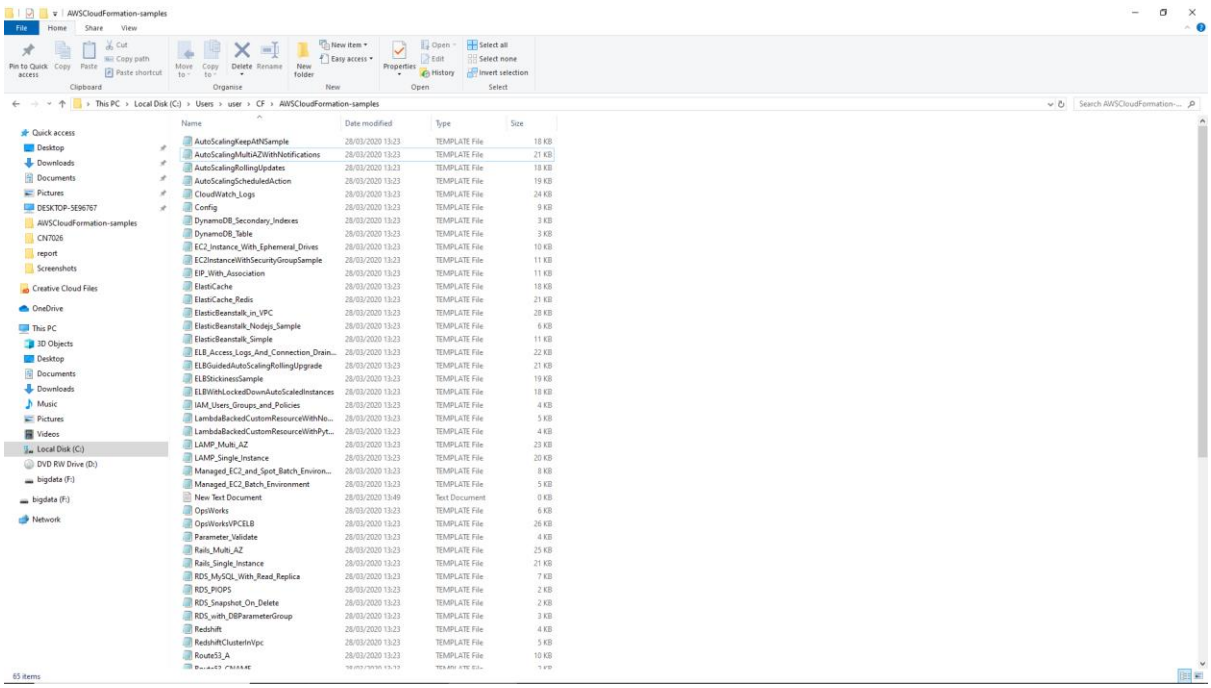
Download template

VPC with private and public subnets



Download template

Folder complete with CloudFormation template library

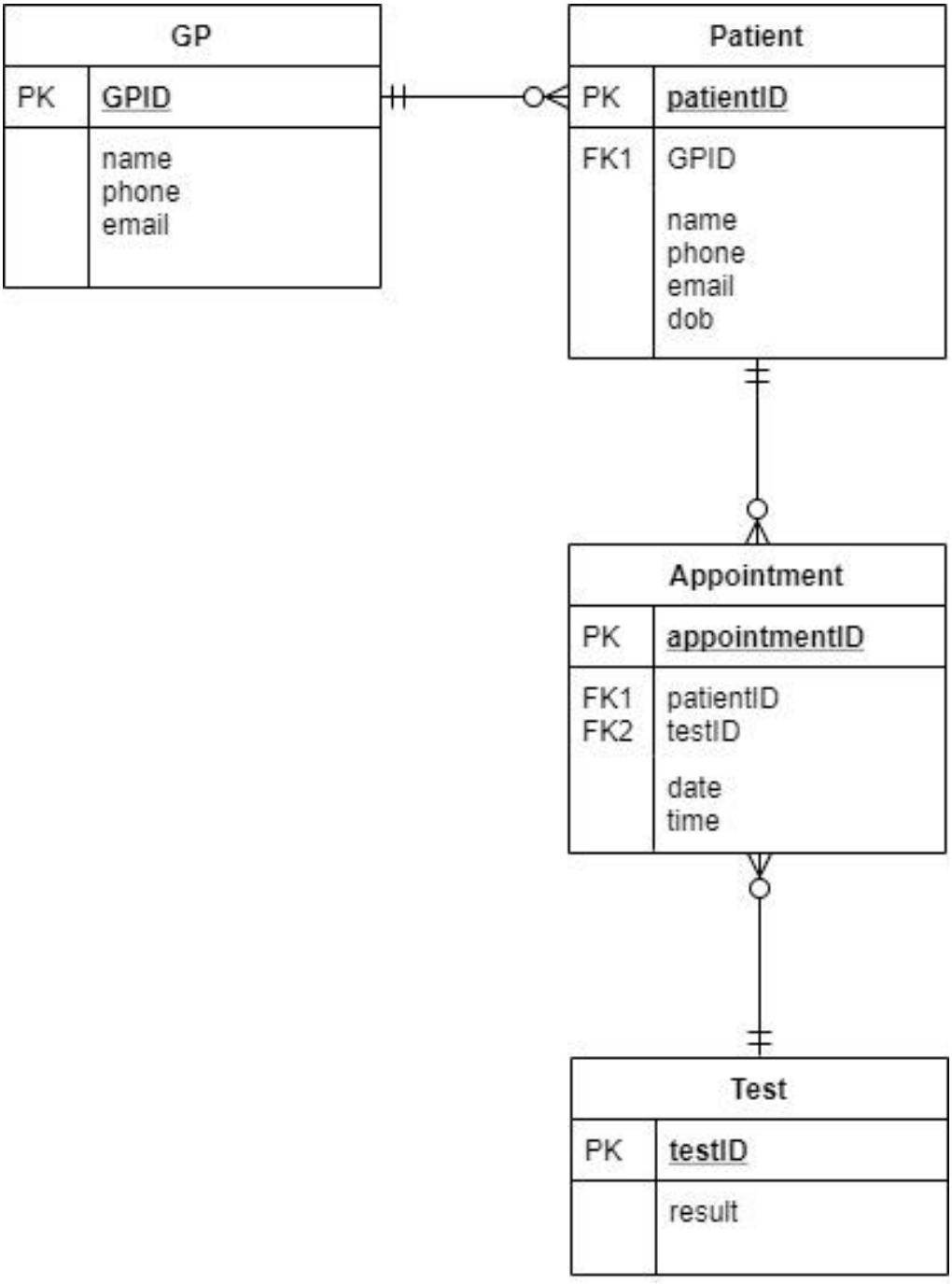


Download folder

Appendix B

2.1 GP-ERD

The Entity Relationship Diagram (ERD) illustrated below represents the RDS database in the GP-VPC. The database tables include; a patient, GP, appointment, and test. The test table was designed to facilitate efficient coronavirus testing, using the RDS service in the GP-VPC.



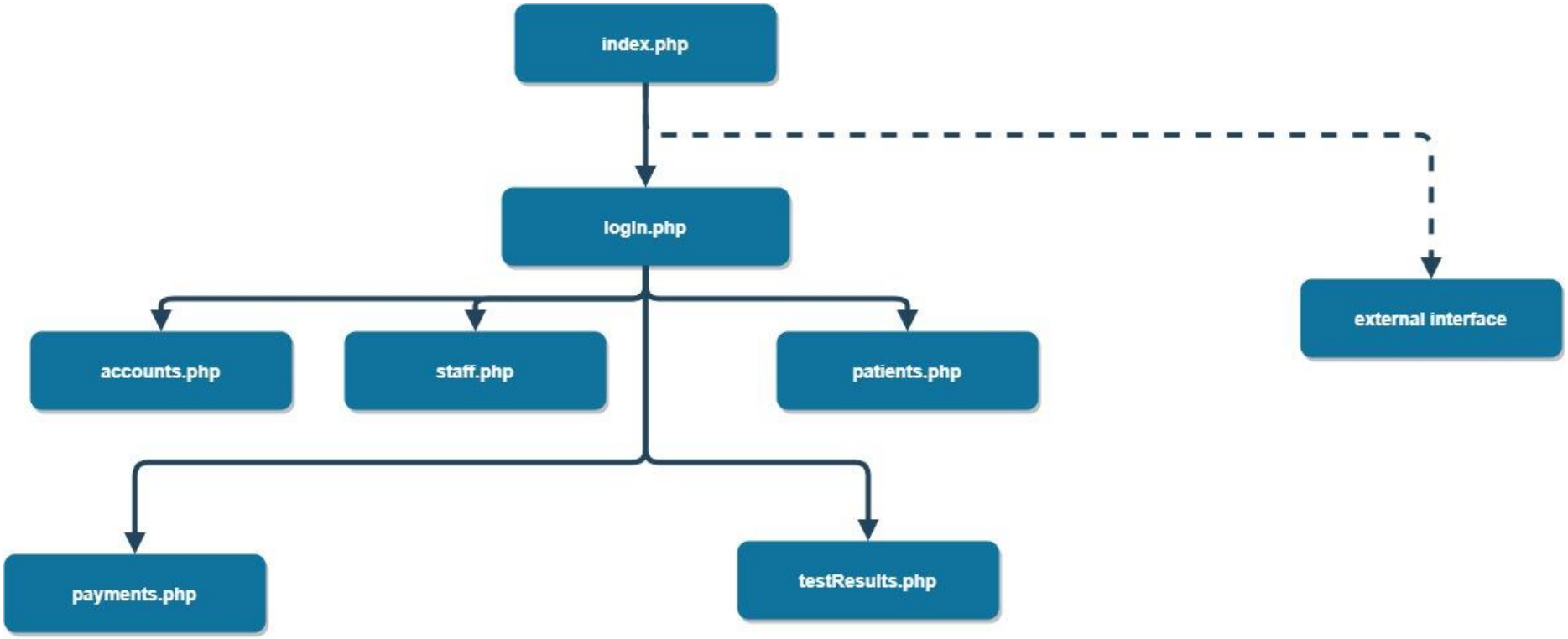
2.2 GPDB.sql

```
CREATE DATABASE gpdb;

USE gpdb;

DROP TABLE IF EXISTS `GP`;

CREATE TABLE `GP` (
  `GPID` int(11) NOT NULL,
  `name` varchar(50) NOT NULL,
  `phone` int(11) NOT NULL,
  `email` varchar(255),
  PRIMARY KEY (`GPID`)
) ENGINE=InnoDB DEFAULT CHARSET=latin1;

INSERT INTO `GP`(`GPID`,`name`,`phone`,`email`) VALUES

(7180,'dr david','7024451838','drdave@mail.com'),
(7181,'dr peter','7022251822','drpeter@mail.com'),
(7182,'dr gurav','7333551118','drgurav@mail.com'),
(7183,'dr hawaad','7025341838','drhawaad@mail.com');

DROP TABLE IF EXISTS `patient`;

CREATE TABLE `patient` (
  `patientID` int(11) NOT NULL,
  `dob` date NOT NULL,
  `name` varchar(50) NOT NULL,
  `phone` int(11) DEFAULT NULL,
  `email` varchar(255),
  `GPID` int(11) DEFAULT NULL,
  PRIMARY KEY (`patientID`),
  KEY `GPID` (`GPID`),
  CONSTRAINT `patient_ibfk_1` FOREIGN KEY (`GPID`) REFERENCES `gp` (`GPID`)
) ENGINE=InnoDB DEFAULT CHARSET=latin1;

INSERT INTO `patient`(`patientID`, `name`, `dob`, `phone`, `email`, `GPID`) VALUES

(1012,'Jean', '2000-01-02', '7025551838','jean@mail.com','7180'),
(1013,'Susie', '1990-03-22','7025551838','sue@mail.com','7182'),
(1014,'Richard', '1967-08-21','7025551838','rich@mail.com','7181'),
(1015,'Paul', '2001-01-02', '7025551838','paul@mail.com','7182'),
(1016,'Gary', '1970-11-05', '7025551838','gary@mail.com','7183'),
(1017,'Andrew', '1959-06-06', '7025551838','asf@mail.com','7180');

CREATE TABLE `appointment` (
  `appointmentID` int(11) NOT NULL,
  `appointmentDate` datetime NOT NULL,
  `testID` int(11) DEFAULT NULL,
  `patientID` int(11) DEFAULT NULL,
```

```
  PRIMARY KEY (`appointmentID`),
  KEY `testID` (`testID`),
  KEY `patient` (`patientID`),
  CONSTRAINT `test_ibfk_1` FOREIGN KEY (`testID`) REFERENCES `test` (`testID`),
  CONSTRAINT `patient_ibfk_2` FOREIGN KEY (`patientID`) REFERENCES `patient` (`patientID`)
) ENGINE=InnoDB DEFAULT CHARSET=latin1;

INSERT INTO appointment (appointmentID, appointmentDate, testID, patientID) VALUES
(9003, '2020-02-05 14:29:36', 30012, 1013),
(9004, '2020-02-05 15:22:26', 30013, 1016),
(9005, '2020-02-06 11:49:38', 30014, 1014);

CREATE TABLE `test` (
  `testID` int(11) NOT NULL,
  `result` BOOLEAN NOT NULL,
  PRIMARY KEY (`testID`)
) ENGINE=InnoDB DEFAULT CHARSET=latin1;

INSERT INTO test (testID, result) VALUES
('30012',true),
('30013',true),
('30014',false);
```

Appendix C

3.1 Website Architecture



3.2 Patient.php

```
<?php include "../inc/dbinfo.inc"; ?>
<html>
<body>
<h1>Patient</h1>
<?php

 /* Connect to MySQL and select the database. */
 $connection = mysqli_connect(DB_SERVER, DB_USERNAME, DB_PASSWORD);

 if (mysqli_connect_errno()) echo "Failed to connect to MySQL: " . mysqli_connect_error();

 $database = mysqli_select_db($connection, DB_DATABASE);

 /* Ensure that the Patient table exists. */
 VerifyPatientTable($connection, DB_DATABASE);

 /* If input fields are populated, add a row to the Patient table. */
 $patient_name = htmlentities($_POST['NAME']);
 $patient_address = htmlentities($_POST['ADDRESS']);

 if (strlen($patient_name) || strlen($patient_address)) {
  Addpatient($connection, $patient_name, $patient_address);
 }
?>

<!-- Input form -->
<form action="<?PHP echo $_SERVER['SCRIPT_NAME'] ?>" method="POST">
 <table border="0">
  <tr>
   <td>NAME</td>
   <td>ADDRESS</td>
  </tr>
  <tr>
   <td>
    <input type="text" name="NAME" maxlength="45" size="30" />
   </td>
   <td>
    <input type="text" name="ADDRESS" maxlength="90" size="60" />
   </td>
   <td>
    <input type="submit" value="Add Data" />
   </td>
  </tr>
 </table>
</form>

<!-- Display table data. -->
<table border="1" cellpadding="2" cellspacing="2">
 <tr>
```

```
   <td>ID</td>
   <td>NAME</td>
   <td>ADDRESS</td>
  </tr>

<?php

$result = mysqli_query($connection, "SELECT * FROM Patient");

while($query_data = mysqli_fetch_row($result)) {
  echo "<tr>";
  echo "<td>",$query_data[0], "</td>",
       "<td>",$query_data[1], "</td>",
       "<td>",$query_data[2], "</td>";
  echo "</tr>";
}
?>

</table>

<!-- Clean up. -->
<?php

  mysqli_free_result($result);
  mysqli_close($connection);

?>

</body>
</html>


<?php

/* Add an patient to the table. */
function Addpatient($connection, $name, $address) {
   $n = mysqli_real_escape_string($connection, $name);
   $a = mysqli_real_escape_string($connection, $address);

   $query = "INSERT INTO Patient (NAME, ADDRESS) VALUES ('$n', '$a');";

   if(!mysqli_query($connection, $query)) echo("<p>Error adding patient data.</p>");
}

/* Check whether the table exists and, if not, create it. */
function VerifyPatientTable($connection, $dbName) {
  if(!TableExists("Patient", $connection, $dbName))
  {
     $query = "CREATE TABLE Patient (
         ID int(11) UNSIGNED AUTO_INCREMENT PRIMARY KEY,
         NAME VARCHAR(45),
```

```
        ADDRESS VARCHAR(90)
       )";

    if(!mysqli_query($connection, $query)) echo("<p>Error creating table.</p>");
  }
}

/* Check for the existence of a table. */
function TableExists($tableName, $connection, $dbName) {
  $t = mysqli_real_escape_string($connection, $tableName);
  $d = mysqli_real_escape_string($connection, $dbName);

  $checktable = mysqli_query($connection,
      "SELECT TABLE_NAME FROM information_schema.TABLES WHERE TABLE_NAME = '$t' AND
TABLE_SCHEMA = '$d'");

  if(mysqli_num_rows($checktable) > 0) return true;

  return false;
}
?>
```

Appendix D

First meeting		
20.02.2020	15:00	ITC04

Meeting called by	Richard
Type of meeting	Group consolidation
Facilitator	Rana
Note taker	Sony
Timekeeper	Sony
Attendees	Sony, Richard, Rana, Supun

Agenda Topic 1	
1 hour	Richard
Discussion	Progress report
Conclusions	Richard demonstrated IAM, SES, CLI, and Elastic Beanstalk. Next week Sony and Nas will discuss progress on disaster recovery or virtualization

Agenda Topic 2		
10 minutes	Sony	
Discussion	Project management	
Conclusions	Sony will take more responsibility. Richard will take less	
	Person	Deadline
Software development – Java/C#	Supun	26.03.20

Agenda Topic 3		
1 hour	Rana	
Discussion	What services are we likely to use	
Conclusions	EC2, lambda, S3 and Elastic Beanstalk	
Task allocation	Person	Deadline
Alexa, S3, RDBMS	Rana	27.02.20
AWS CLI, SES, IAM	Richard	27.02.20
AWS SDK for Java, Lambda	Supun	27.02.20
Disaster recovery and Virtualization	Sony	27.02.20

Second meeting		
27.02.2020	15:00	ITC04

Meeting called by	Richard
Type of meeting	Group progress
Facilitator	Rana
Note taker	Sony
Timekeeper	Sony
Attendees	Sony, Richard, Rana, Supun
Agenda Topic 1	
1 hour	Richard
Discussion	Progress report
Conclusions	Sony discussed virtualization and explained how it could be used in our project. Rana discussed EC2 and gave examples of how it could be used in our project. Richard discussed the 5 pillars of a well architecture framework, and shared examples of the research we need to complete.
Agenda Topic 2	
30 minutes	Rana
Discussion	Database development and documentation
Conclusions	Richard shared examples of previous projects, Rana and Supun agreed to base their work on the 5 pillars.
Agenda Topic 3	
1 hour	Sony
Discussion	Virtualization
Conclusions	The group all understand the benefits

Task allocation	Person	Deadline
Alexa, S3, RDBMS, Performance pillar	Rana	05.03.20
AWS Lambda, S3, RDBMS, Security pillar	Richard	05.03.20
Node JS, Operational excellence pillar	Supun	05.03.20
Disaster Recovery, Reliability pillar	Sony	05.03.20

Progress meeting		
05.03.2020	15:00	ITC04

Meeting called by	Sony
Type of meeting	Group progress
Facilitator	Rana
Note taker	Richard
Timekeeper	Supun
Attendees	Sony, Richard, Rana, Supun
Agenda Topic 1	
30 minutes	Richard
Discussion	GP Cloud Migration, Data Flow and Use Case Examples
Conclusions	Richard created a vpc-rds-ec2 system and demonstrated updating the database and web pages. **Complete GP requirements analysis**
Agenda Topic 2	
30 minutes	Rana and Supun
Discussion	Database development and documentation
Conclusions	**Complete GP and DB requirements analysis**
Agenda Topic 3	
30 minutes	Sony
Discussion	draw.io
Conclusions	use draw.io and update the reliability.doc – use own words

Task allocation	Person	Deadline
DB Development, Performance, Cost	Rana	12.03.20
DynamoDB, Security, Lambda, Kinesis, Cost, CloudFront, System Architecture	Richard	12.03.20
Node JS, Operations, DB Development, Cost	Supun	12.03.20
Reliability, draw.io, Cost	Sony	12.03.20

Progress meeting		
12.03.2020	15:00	ITC04

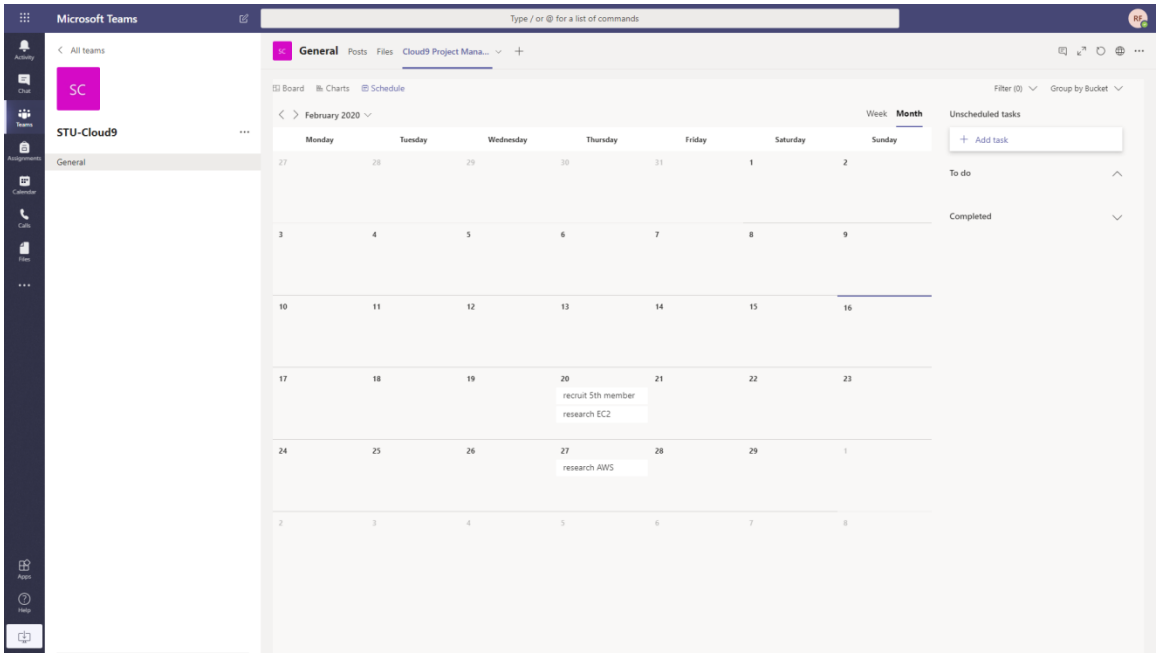
Meeting called by	Rana
Type of meeting	Group progress
Facilitator	Rana
Note taker	Richard
Timekeeper	Richard
Attendees	Richard, Rana
Agenda Topic 1	
30 minutes	Richard
Discussion	Progress Report
Conclusions	Richard modelled the vpc and documented the development process. Rana and Supun modelled the database and shared with the group. Sony sent a template **GP requirements analysis is incomplete**
Agenda Topic 2	
30 minutes	Rana and Supun
Discussion	Database development and documentation
Conclusions	**GP and DB requirements analysis are incomplete**
Agenda Topic 3	
30 minutes	Richard
Discussion	reliability
Conclusions	update the reliability.doc – use own words

Task allocation	Person	Deadline
DB Development, Performance	Rana	19.03.20
RDS, Security, CloudFront, CloudTrail, System Architecture, IAM, System Documentation	Richard	19.03.20
Node JS, Operations, DB Development	Supun	19.03.20
Reliability	Sony	19.03.20

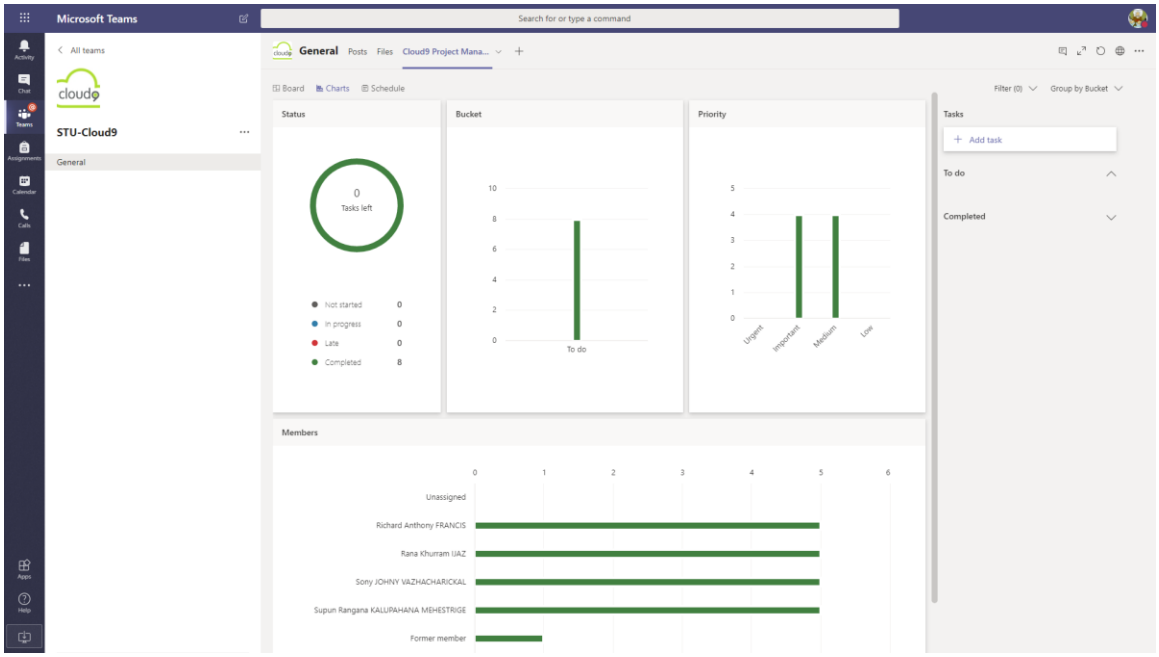
Project Management Documentation

Due to the virus outbreak group work was suspended. However, it is important to note that the schedule was kept, and tasks were completed on time.

Project schedule



Project progress



Appendix E

5.1 CloudTrail Logs

The logs highlighted below are a real life example. Using these logs administrators and business owners ca audit, analyse and decide what future actions or processes are required to improve the system.

Log file example

```
85446540137b3a81572684bbf84a43d53837bf7ae4f788b474c64913127ac5b5 research-aws [09/Mar/2020:03:24:40 +0000] 188.31.92.221 85446540137b3a81572684bbf84a43d53837bf7ae4f788b474c64913127ac5b5 3F5B8224B83A2CAE REST.GET.ACL - "GET /?acl HTTP/1.1" 200 - 480 - 5 - "-" "S3Console/0.4, aws-internal/3 aws-sdk-java/1.11.719 Linux/4.9.184-0.1.ac.235.83.329.metal1.x86_64 OpenJDK_64-Bit_Server_VM/25.242-b08 java/1.8.0_242 vendor/Oracle_Corporation" - 4EXxoHL/D1Cf0hp96y9HNZNFK47wbbOqNVb8I0bHOZYO2dP/xGpMVP/L/ruIJqgvfoKN3Tvk3so= SigV4 ECDHE-RSA-AES128-SHA AuthHeader research-aws.s3.eu-west-2.amazonaws.com TLSv1.2
```

5.2 IAM.json

Using json type files IAM administrators and business owners can restrict access to AWS resources. Temporary access may be provided; roles and groups are also used.

JSON file example

```
{
  "Version": "2012-10-17",
  "Statement": {
    "Effect": "Allow",
    "Action": "dynamodb:*",
    "Resource": "arn:aws:dynamodb:us-east-2:ACCOUNT-ID-WITHOUT-HYPHENS:table/${aws:username}"
  }
}
```

5.3 Micro Services

Application Load Balancer:	Integrated with CloudWatch to ensure traffic is directed to healthy instances.
Auto Scaling Group:	Adjusting capacity to meet demand and provide a layer of security using security groups.
NAT Gateway:	You can use a network address translation (NAT) gateway to enable instances in a private subnet to connect to the internet or other AWS services, but prevent the internet from initiating a connection with those instances. A NAT gateway can support up to 55,000 simultaneous connections to each unique destination.
Internet Gateway:	A horizontally scaled redundant and highly available VPC component that allows communication between instances in the VPC and the internet
Subnets:	Private and public range of IP addresses in the GP-VPC
Route Table:	Specify how network traffic is directed from within the VPC.
Network Interface:	Gives the web server a public IP address • Elastic IP Addresses: An *Elastic IP address* is a static, public IPv4 address designed for dynamic cloud computing. You can associate an Elastic IP address with any instance or network interface for any VPC in your account.
Security Groups:	Control inbound and outbound traffic for the instances
Network ACL's	Control inbound and specify deny for outbound traffic for your subnets. Must be subnet level.
Flow Logs:	Capture the traffic that flows to and from the network interfaces.
Endpoints	A VPC endpoint enables you to privately connect your VPC to supported AWS services.

5.4 Resources

The following lists the services used and tutorials completed while creating the GP-VPC environment. This list does not include resources highlighted in the report.

Walkthrough: Use AWS CloudFormation Designer to Create a Basic Web Server
https://docs.aws.amazon.com/AWSCloudFormation/latest/UserGuide/working-with-templates-cfn-designer-walkthrough-createbasicwebserver.html

Walkthrough: Create a Scalable, Load-balancing Web Server
https://docs.aws.amazon.com/AWSCloudFormation/latest/UserGuide/example-templates-autoscaling.html

Tutorial: Create a Web Server and an Amazon RDS Database
https://docs.aws.amazon.com/AmazonRDS/latest/UserGuide/TUT_WebAppWithRDS.html

Deploying a high-availability PHP application with an external Amazon RDS database to EB
https://docs.aws.amazon.com/elasticbeanstalk/latest/dg/php-ha-tutorial.html

Configuring a Static Website Using a Custom Domain Registered with Route 53
https://docs.aws.amazon.com/AmazonS3/latest/dev/website-hosting-custom-domain-walkthrough.html#add-bucket-policy-root-domain

CloudFront Documentation: Configuring Secure Access and Restricting Access to Content
https://docs.aws.amazon.com/AmazonCloudFront/latest/DeveloperGuide/SecurityAndPrivateContent.html

Tutorial: Schedule AWS Lambda Functions Using CloudWatch Events
https://docs.aws.amazon.com/AmazonCloudWatch/latest/events/RunLambdaSchedule.html

CloudWatch Documentation: Create Alarms to Stop, Terminate, Reboot, or Recover an Instance
https://docs.aws.amazon.com/AmazonCloudWatch/latest/monitoring/UsingAlarmActions.html#AddingStopActions

Build a Serverless Web Application with AWS Lambda, Amazon API Gateway, Amazon S3, Amazon DynamoDB, and Amazon Cognito
https://aws.amazon.com/getting-started/hands-on/build-serverless-web-app-lambda-apigateway-s3-dynamodb-cognito/

Example: Create an IPv4 VPC and Subnets Using the AWS CLI
https://docs.aws.amazon.com/vpc/latest/userguide/vpc-subnets-commands-example.html

Tutorial: Use CodeDeploy to Deploy an Application to an Amazon EC2 Auto Scaling Group
https://docs.aws.amazon.com/codedeploy/latest/userguide/tutorials-auto-scaling-group.html

Using AWS Lambda with Amazon S3 Events
https://docs.aws.amazon.com/lambda/latest/dg/with-s3.html

IAM Best Practices
https://docs.aws.amazon.com/IAM/latest/UserGuide/best-practices.html

Automated Response and Remediation with AWS Security Hub
https://aws.amazon.com/blogs/security/automated-response-and-remediation-with-aws-security-hub/

Create a Network File System with Amazon Elastic File System (EFS)
https://aws.amazon.com/getting-started/tutorials/create-network-file-system/?trk=gs_card

Send an Email with Amazon SES
https://aws.amazon.com/getting-started/hands-on/send-an-email/

Tutorial: Launch and configure a LAMP instance in Amazon Lightsail
https://lightsail.aws.amazon.com/ls/docs/en_us/articles/amazon-lightsail-tutorial-launching-and-configuring-lamp

Well Architected - Learn, measure, and build using architectural best practices
https://aws.amazon.com/architecture/well-architected/

Internetwork Traffic Privacy in Amazon VPC

https://docs.aws.amazon.com/vpc/latest/userguide/VPC_Security.html

Security Best Practices for Your VPC

https://docs.aws.amazon.com/vpc/latest/userguide/vpc-security-best-practices.html

Get Started with Amazon SageMaker Notebook Instances and SDKs

https://docs.aws.amazon.com/sagemaker/latest/dg/gs-console.html

Store, Protect, Optimize Your Healthcare Data with AWS: Part 1

https://aws.amazon.com/blogs/architecture/store-protect-optimize-your-healthcare-data-with-aws/

Store, Protect, Optimize Your Healthcare Data with AWS: Part 2

https://aws.amazon.com/blogs/architecture/store-protect-optimize-your-healthcare-data-with-aws-part-2/

Healthcare & Life Sciences

https://aws.amazon.com/health/

CSSE COVID-19 Dataset

https://github.com/CSSEGISandData/COVID-19/tree/master/csse_covid_19_data

Tutorial: Using AWS Lambda with Amazon Kinesis

https://docs.aws.amazon.com/lambda/latest/dg/with-kinesis-example.html

Resize an Image in AWS S3 Using a Lambda Function

https://levelup.gitconnected.com/resize-an-image-in-aws-s3-using-lambda-function-dc386afd4128